COMPUTERIZED ENGINE CONTROLS

EIGHTH EDITION

STEVE V. HATCH

COMPUTERIZED ENGINE CONTROLS

Eighth Edition

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Eighth Edition
Steve V. Hatch

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Preface

The application of the microprocessor with its related components and circuits has made automotive technology exciting, fast paced, and more complicated. Recent technological developments and those that will follow require entry-level automotive service technicians to be well trained in the principles of automotive technology and to be career-long students. Those who respond to this requirement will find the task challenging but achievable and rewarding.

This text was written in response to a widely recognized need within the industry: to help student-technicians get a commanding grasp of how computerized engine control systems work and how to diagnose problems within them. The student-technician who studies this text will soon come to realize that no single component or circuit on any given computerized engine control system, other than the computer itself, is complicated.

Computerized Engine Controls is written with the assumption that the reader is familiar with the basic principles of traditional engine, electrical system, and fuel system operation. Although everything here is within the grasp of a good technician, this is not a beginner's book.

A computerized engine control system does in fact become an integral part of an engine's electrical and fuel system, but it is much too significant and complex to be taught as just a single unit in an engine performance textbook or class. For purposes of instruction, we have taken this topic out of context and examined it as a stand-alone control system. Once the student-technician fully understands the system's purpose, operation, and diagnostic approach, the diagnostic procedures in the service manual will put the system back in its proper perspective as an integral part of the engine's support system.

Computerized Engine Controls presents each popular, multifunction computer control system in a separate chapter. Each system is fully covered, with enough specific information and detail to enable the reader to get a complete and clear picture of how the system works. This text is written with the premise that understanding how the overall system works, and what it should be doing, not only makes the diagnostic process easier, but also makes the diagnostic literature much easier to understand. Correctly interpreting directions for diagnostic procedure is often a problem if the technician is not aware of what the procedure is trying to measure, what normal readings or responses should be, or what conditions will cause abnormal readings or responses.

The chapters of this edition contain:

- *Objectives.* Objectives are provided at the beginning of each chapter to help the reader identify the major concepts to be presented.
- *Key Terms.* Terms that are unique to computerized engine control systems are provided at the beginning of each chapter as Key Terms and then appear in **boldface** type at their first use in the chapter. These Key Terms are also provided in the Glossary, along with their definitions.

- *Diagnostic & Service Tips.* These tips offer helpful advice for the technician on diagnosing and servicing vehicles, as well as addressing customer concerns.
- *Chapter Articles.* Chapter Articles give additional nice-to-know information about technical topics covered in the chapter.
- *Summary.* Each chapter contains a Summary near the end to review the major concepts presented in that chapter.
- *Diagnostic Exercise.* A Diagnostic Exercise is provided near the end of each chapter, applying a real-life scenario to one of the concepts covered in that chapter.
- *Review Questions.* Review Questions are provided at the end of each chapter to help a reader assess his/her recall and comprehension of the material read in each chapter, as well as to reinforce the concepts covered in each chapter. Without exception, all of these Review Questions have been written in a multiple-choice format, the type of question that would be found on an ASE test.

Personal safety concerns peculiar to specific computerized engine control systems are highlighted where applicable. The book follows the industry standards for how to use the following terms:

- **Warnings** indicate that failure to observe correct diagnostic or repair procedures could result in personal injury or even death.
- **Cautions** indicate that failure to observe correct diagnostic or repair procedures could result in damage to tools, equipment, or the vehicle being serviced.

Each student should be aware that while working with computerized controls is not inherently dangerous, failure to observe recognized safety practices is. There are, unfortunately, many more injuries and accidents in the automotive repair business than there should be. Good safety practices, if learned early in a student's career, literally can be lifesaving later on.

New to This Edition

In accordance with several reviewers' requests, the original introduction has been transformed into the new Chapter 1 with chapter questions following. This chapter has been updated in several areas so as to help electrical concepts come alive for the reader. With Chapter 1 having laid the foundation for understanding semiconductors, Chapter 2 now includes a discussion of *logic gates* so as to help take the magic out of the computer.

Countless other changes have also been made throughout this textbook. The chapters with the most changes are the generic chapters—Chapters 1 through 9 and Chapter 18—although some information was updated in the manufacturer-specific chapters as well, particularly Chapters 12, 14, and 17. Appendix A has been revised to flow more efficiently for the reader. And one more appendix has been added, Appendix C, with a list of some automotive-related web addresses. These changes and additions have been made so as to make this textbook the most comprehensive automotive textbook that you will read this year.

SUGGESTIONS ON HOW TO USE THIS TEXT

The reader should begin by reading Chapters 1 through 9, preferably in the sequence they exist in the textbook, as they contain information that pertains to all makes of vehicles. Reading these chapters will also provide some background that will make understanding specific system designs and diagnostic strategies easier when reading the product-specific chapters of this book. The remaining chapters, which are specific to individual systems, can be read in any order, though most students will find it much easier to read a manufacturer's set of chapters in chronological sequence, the way they appear in the book. Generally, systems become more complex over time. The newer, more complex systems become easier to understand if the reader has proficient background knowledge of the earlier, simpler systems. Many students may not wish to study each specific chapter, or their instructors may not choose to assign the study of each chapter. We suggest, however, that at least three of the specific system chapters be selected for study. Remaining chapters can then be skimmed or serve as a reference for future use.

Finally, "Appendix A: Approach to Diagnostics," which offers a strategy-based diagnostic approach, should be read to help the reader apply the information contained within the chapters of this book to a live vehicle. "Appendix B: Terms and Acronyms" provides a central location where the reader can look up many of the terms and acronyms that relate to automotive electronic systems. And, as noted earlier, the new Appendix C contains a list of automotive-related web addresses.

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Acknowledgments

I am very honored to be able to present a textbook of such magnitude as this. But there are those around me that I depend on greatly and without whom this textbook would not be the success it is today.

Many thanks to my family, my friends, and my colleagues who have so encouraged me. And many thanks to my students who, while they were in my classes over the years, asked the right questions that encouraged me to "find the answer."

I would like to thank the following people for their efforts on the behalf of this textbook:

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Chapter 1

A Review of Electricity and Electronics

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

☐ Understand the conceptual differences between the terms *electrical* and *electronic.*
☐ Understand how a compound is different from an element.
☐ Define the difference between an element and a compound.
☐ Describe the importance of an atom's valence ring as it pertains to electrical theory.
☐ Understand the relationship between voltage, resistance, and amperage.
☐ Define circuit types in terms of series circuits and parallel circuits.
☐ Understand the construction and operation of semiconductors such as diodes and transistors.
☐ Define the difference between an analog voltage signal and a digital voltage signal.
☐ Describe the relationship between a variable frequency, variable duty cycle, and variable pulse width.

KEY TERMS

Amp or Ampere
Amperage
Armature
Clamping Diode
Compound
Diode
Dual In-Line Package (DIP)
Electrical
Electromotive Force
Electronic
Element
Free Electrons
H-Gate
Integrated Circuit (IC)
Molecule
Negative Ion
Ohm
Ohm's Law
Permeability
Positive Ion
Reluctance
Resistance
Semiconductors
Solenoid
Transistor
Valence Ring
Volt
Voltage or Voltage Potential
Voltage Drop

The earliest automobiles had little in the way of **electrical** systems, but as the automobile has become more complicated and as more accessories have been added, electrical and **electronic** systems have replaced mechanical methods of control on today's vehicles. Additional electronic control systems have made and will continue to make the automobile comply with government standards and consumer demands. Today, most major automotive systems are controlled by computers.

This increased use of electrical and electronic systems means two things for the automotive service technician: First, to be effective, all service technicians need skills in electrical diagnosis and repair, almost regardless of the technician's service specialty; second, technicians with such skills will command significantly greater financial rewards and will deserve them.

There are several principles by which electrical systems operate, but they are all fairly simple; learning them is not difficult. As each principle is introduced to you through your reading or in class, ask questions and/or read until you understand it. Review the principles frequently and practice the exercises that your instructor assigns.

ELECTRICAL CIRCUITS VERSUS ELECTRONIC CIRCUITS

The differences between electrical circuits and electronic circuits are not always clear-cut. This has led to some confusion about the use of terms and how an electronic system differs from an electrical system. Perhaps the comparisons in the following table will help.

Think of electrical circuits as the *muscle* and electronic circuits as the *brain.* Electrical circuits have been used in the automobile since the first one came off the assembly line, but electronic circuits have been added to the automobile in more recent years. For example, interior lighting circuits began on the automobile as simple electrical circuits and without any electronic control. But, more often than not, interior lighting systems on today's vehicles are controlled electronically by a computer.

Even though the use of solid-state components may often be used as a criterion to identify an electronic circuit, solid-state components, such as a *power transistor,* may also be used in an electrical circuit. A power transistor is a type of transistor designed to carry larger amounts of **amperage** than are normally found in an electronic circuit. A power transistor is essentially a highly reliable relay.

Ultimately, an electrical circuit is a circuit that performs work through a load device. An electronic circuit is used to intelligently control an electrical circuit. Therefore, an electrical circuit may or may not be under the control of an electronic circuit.

It should also be noted that a component identified as an *electronic* device always needs a proper power (positive) and ground (negative) just to power up properly, whether it is a small **integrated circuit** (IC) chip or a complex, sophisticated computer. If either one is lacking it cannot do its assigned job properly.

Electrical Circuits	Electronic Circuits
Do physical work: heat, light, and electromagnetism used to create movement.	Communicate information: voltages or on/off signals.
Use electromechanical devices: motors, solenoids, relays.	Use solid-state devices (semiconductors) with no moving parts, such as transistors and diodes.
Operate at relatively high current or amperage.	Operate at relatively low current or amperage.
Have relatively low resistance (ohms).	Have relatively high resistance (ohms).
May or may not be controlled by an electronic circuit.	Are used to control electrical circuits.

ELECTRON THEORY

Molecules and Atoms

A study of electricity begins with the smallest pieces of matter. All substances—air, water, wood, steel, stone, and even the various substances that our bodies are made of—are made of the same bits of matter. Every substance is made of units called **molecules.** A molecule is a unit formed by combining two or more atoms; it is the smallest unit that a given substance can be broken down to and still exhibit all of the characteristics of that substance. For example, a molecule of water, or H_2O, is made up of two atoms of hydrogen and one atom of oxygen (H is the chemical symbol for hydrogen and O is the chemical symbol for oxygen). If a molecule of water is broken down into its component atoms, it is no longer water.

As molecules are made up of atoms, atoms are in turn made up of:

- electrons, or negatively charged particles,
- protons, or positively charged particles,
- neutrons, or particles with no charge; at the level of atomic activity concerning us here, neutrons just add mass to the atom.

The smallest and lightest atom is the hydrogen atom. It contains one proton and one electron (Figure 1–1); it is the only atom that does not have a neutron. The next smallest and lightest atom is the helium atom. It has two protons, two neutrons, and two electrons (Figure 1–2). Since the hydrogen atom is the smallest and lightest, and since it has one electron and one proton, it is given an atomic number of 1. Since helium is the next lightest, it has an atomic number of 2. Every atom has been given an atomic number that indicates its relative size and weight (or its mass) and the number of electrons, protons, and neutrons it contains. An atom usually has the same number of electrons, protons, and neutrons.

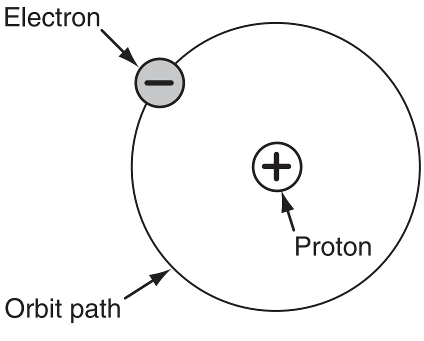


Figure 1–1 Hydrogen atom.

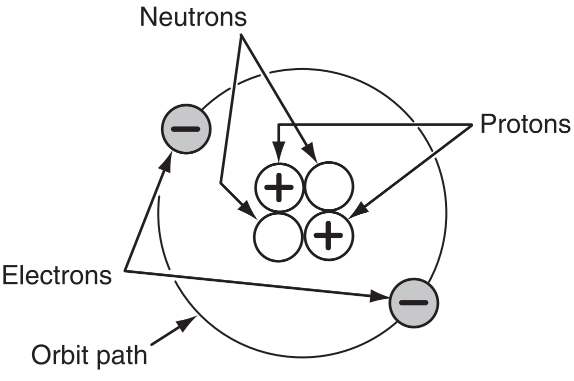


Figure 1–2 Helium atom.

Elements

Once the three different bits of matter are united to form an atom, two or more atoms combine to form a molecule. If all of the atoms in the molecule are the same, the molecule is called an **element.** Which element it is depends on how many protons, neutrons, and electrons the atoms contain. There are more than a hundred different elements. Some examples of elements are gold, lead, iron, and sodium. Examples of other elements that are of concern to an automotive technician include hydrogen, carbon, nitrogen, oxygen, and silicon. An element, then, is a pure substance whose molecules contain only one kind of atom.

Compounds

A substance such as water, which contains hydrogen and oxygen atoms, is called a **compound.** Examples of other compounds that are of concern to an automotive technician include carbon dioxide, carbon monoxide, hydrocarbons, and oxides of nitrogen. Therefore, compounds consist of two or more elements.

Molecules

A molecule consists of a minimum of two atoms that are chemically bonded together; it is electrically stable, with a neutral charge. A molecule may contain two or more identical atoms and therefore be an element, such as an oxygen molecule (O_2), or it may have atoms of two or more elements and therefore be a compound, such as water (H_2O).

Atomic Structure and Electricity

Notice in Figures 1–1 and 1–2 that the protons and neutrons are grouped together in the center of each atom, which is called the *nucleus* of the atom. The electrons travel around the nucleus of the atom in an orbit, similar to the way that the Earth travels around the sun. But because an atom usually has several electrons orbiting around its nucleus, the electrons form in layers, rather than all of them traveling in the same orbit (Figure 1–3). Some, however, share the same orbit, as seen in Figure 1–3. For the purpose of this text, only the electrons in the last layer are of any real importance. This layer is often called the *outer shell* or **valence ring.** The student should realize that we are speaking very loosely here when we describe electrons in shells having orbits. For our purposes, this simple explanation (a model once called the *Rutherford atom*) satisfactorily conveys the nature of the electron.

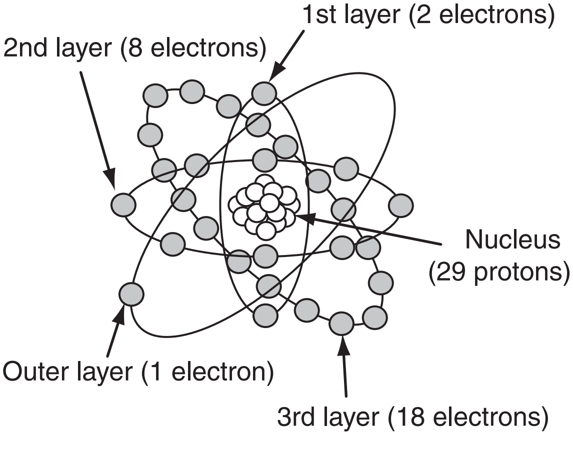


Figure 1–3 Layers of electrons around a copper atom nucleus.

As mentioned, electrons are negatively charged and protons are positively charged. You have probably heard or know that like charges repel and unlike charges attract. Electrons are always moving; in fact, they are sometimes said to move at nearly the speed of light. These characteristics work together to explain many of the behaviors of an atom that make current flow. *Current* is defined as a mass of **free electrons** moving in the same direction.

There are two types of current: *direct current (DC)* and *alternating current (AC).* Direct current always flows in one direction. Current from a battery is the best example. Most of the devices in an automobile use DC. Circuits with alternating current repeatedly switch the polarity of the circuit so that current flow (electron movement) reverses direction repeatedly. The power available from commercial utility companies is AC and cycles (changes *polarity*) 60 times per second. This is known as 60 Hertz (Hz) AC voltage. One cycle occurs when the current switches from forward to backward to forward again. The car's alternator (an AC generator) produces AC current, which is converted to DC before it leaves the alternator.

The fast-moving electron wants to move in a straight line, but its attraction to the proton nucleus makes it act like a ball tied to the end of a string twirled around. The repulsive force between the electrons keeps them spread as far apart as their attraction to the nucleus will allow.

The fewer electrons there are in the outer shell of the atom and the more layers of electrons there are under the outer shell, the weaker is the bond between the outer electrons and the nucleus. If one of these outer electrons can somehow be broken free from its orbit, it will travel to a neighboring atom and fall into the outer shell there, resulting in two unbalanced atoms. The first atom is missing an electron. It is now positively charged and is called a **positive ion.** The second atom has an extra electron. It is negatively charged and is called a **negative ion.** Ions are unstable. They want either to gain an electron or to get rid of one so that they are balanced.

ELECTRICAL THEORY

Voltage Potential

An atom that is a positive ion has positive *potential.* It has more positive charge than negative charge because it has more protons than electrons. Suppose that this atom is at one end of a circuit (Figure 1–4). Further suppose that there is a negative ion at the other end of the circuit in that this atom has an extra electron, thus giving it a negative potential. Because of the *difference* in potential at the two ends of the circuit, an electron at the negatively charged end will start moving toward the positively charged end. The greater the difference in potential (the greater the number of opposite-charged ions) at each end of the circuit, the greater the number of electrons that will start to flow. This potential difference between the two charges is commonly known as **voltage potential.**

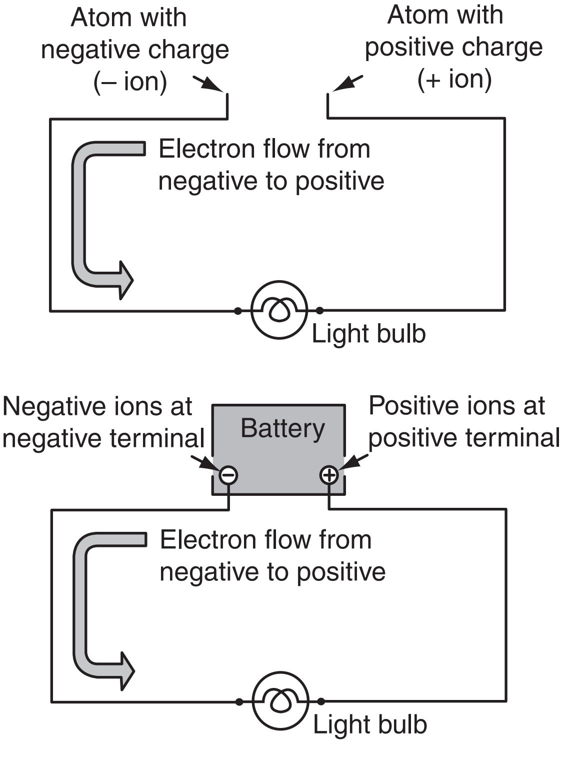

Atom with negative charge (– ion)
Atom with positive charge (+ ion)
Electron flow from negative to positive
Light bulb
Negative ions at negative terminal
Battery
Positive ions at positive terminal
Electron flow from negative to positive
Light bulb

Figure 1–4 Negative versus positive potential.

An example can be created by attaching something between the two ends of a circuit that will produce positive and negative ions. This is what a battery or generator does in a circuit (Figure 1–4). If you connect both ends of a copper wire to a battery, the voltage potential will cause electron flow through the wire. However, because the wire will not be able to handle the electron flow that the battery can provide, it will burn open very quickly. Therefore some kind of **resistance,** or opposition to a steady electric current, is needed in the wire. Actually, this resistance has two functions. It limits current flow so as to keep the wire from burning open and it also turns the current flow into some type of useful work—heat, light, or electromagnetism.

It is the voltage potential that makes current flow. Actually, three factors must be present for an electrical circuit to work properly. These three factors are voltage potential, resistance to flow, and current flow, as demonstrated in the following example:

> Suppose that you have a glass of your favorite lemonade sitting on your patio table on a nice summer day. Suppose that there is a straw sitting in the glass of lemonade. There is atmospheric pressure acting on the lemonade in the glass and therefore at the lower end of the straw. There is also atmospheric pressure present at the upper end of the straw (remember, it is just sitting there on the patio table at the moment). Because there is no potential difference between the pressures at the two ends of the straw, the lemonade is not presently flowing in the straw. Now, if you simply close your mouth over the upper end of the straw but do not change the pressure in your mouth, you

will still not get the lemonade to flow up the straw. You must provide a pressure difference (or potential) in order to get the lemonade to flow up the straw. You do this by creating a negative pressure within your mouth (that is, a pressure that is less than the atmospheric pressure acting on the lemonade in the glass). The pressure differential is what causes the lemonade to flow up the straw. If you want to get a larger flow of lemonade, you must create a larger pressure difference (or suck harder). However, this only tells half the story. Another factor that influences the volume of lemonade that you get to flow up the straw is the size of the straw. Suppose that you replace your normal size straw with a slender coffee stir stick/straw. This small straw would limit the volume of lemonade that you could get to flow up the straw. The same is true in an electrical circuit. In an electrical circuit, the amount of current that flows is dictated by two factors—how much voltage potential is applied to the circuit and how much resistance to flow is present in the circuit. This is, in essence, what is commonly known as **Ohm's law,** described later in this chapter. You can also apply this same principle to a fuel injector in that the flow rate of a fuel injector is dictated by the amount of pressure difference between the two ends of the injector and the orifice size (restriction) of the injector.

Magnetism

Magnetism is closely tied to the generation and use of electricity. In fact, one of the prevailing theories is that magnetism is caused by the movement and group orientation of electrons. Some materials strongly demonstrate the characteristics associated with magnetism and some do not. Those that strongly demonstrate the characteristics of magnetism, such as iron, are said to have high **permeability.** Those that do not, such as glass, wood, and aluminum, are said to have high **reluctance.**

Lines of Force

It is not known whether there actually is such a thing as a *magnetic line of force.* What is known, however, is that magnetism exerts a force that we can understand and manipulate if we assume there are magnetic lines of force. Magnetic force is linear in nature and it can be managed to do many kinds of work. By assigning certain characteristics to these lines of force, the behavior of magnetism can be explained. Magnetic lines of force:

1. have a directional force (north to south outside the magnet),
2. want to take the shortest distance between two poles (just like a stretched rubber band between the two points from which it is held),
3. form a complete loop,
4. are more permeable to iron than air,
5. resist being close together (especially in air),
6. resist being cut,
7. will not cross each other (they will bend first).

Magnetic lines of force extending from a magnet make up what is commonly called a magnetic field and more correctly called magnetic *flux* (Figure 1–5). If a magnet is not near an object made

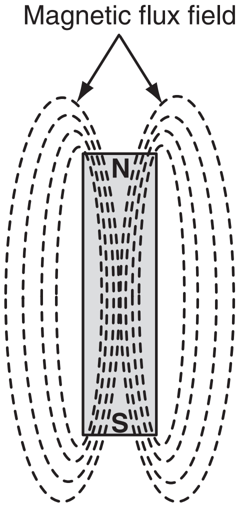


Figure 1–5 Magnetic field.

of permeable material, the lines of force will extend from the north pole through the air to the south pole (characteristic 1). The lines of force will continue through the body of the magnet to the north pole to form a complete loop (characteristic 3). Every magnet has a north pole and a south pole. The poles are the two points of a magnet where the magnetic strength is greatest. As the lines of force extend out of the north pole, they begin to spread out. Here you see opposition between characteristics 2 and 5. The lines of force want to take the shortest distance between the poles, but they spread out because of their tendency to repel each other (characteristic 5). The result is a magnetic field that occupies a relatively large area but has greater density near the body of the magnet.

Because the body of the magnet has high permeability, the lines of force are very concentrated in the body of the magnet (characteristic 4). This accounts for the poles of the magnet having the highest magnetic strength.

If there is an object with high permeability near the magnet, the magnetic lines of force will distort from their normal pattern and go out of their way to pass through the object (Figure 1–6). The tendency for the lines of force to pass through the permeable object is stronger than their tendency to take the shortest route. The lines of force will, however, try to move the object toward the nearest pole of the magnet.

Electromagnets

Early researchers discovered that when current passes through a conductor, a magnetic field forms around the conductor (Figure 1–7). This principle makes possible the use of electromagnets, electric motors, generators, and most of the other components used in electrical circuits.

If a wire is coiled with the coils close together, most of the lines of force wrap around the entire coil rather than going between the coils of wire (Figure 1–8). This is because if they do try to wrap around each loop in the coil, they must cross each other, which they will not do (characteristic 7) (Figure 1–9).

If a high-permeability core is placed in the center of the coil, the magnetic field becomes much stronger because the high-permeability core replaces low-permeability air in the center

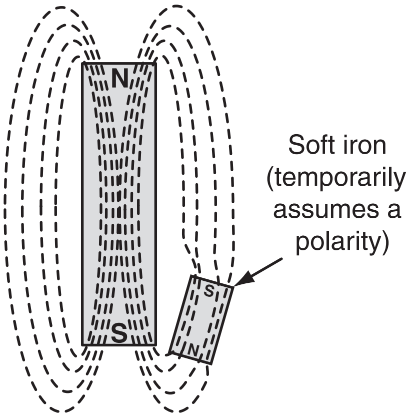
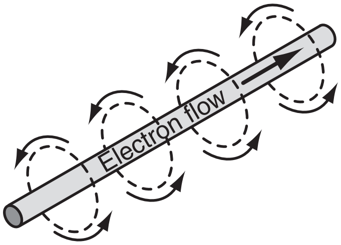
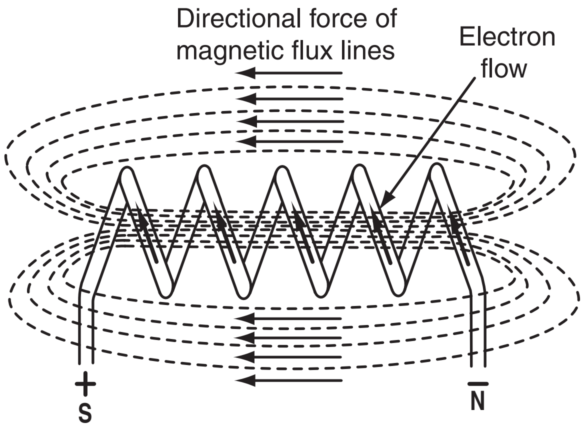


Figure 1–6 Magnetic field distortion. If you place your left hand on the wire with your thumb pointing in the direction of electron flow, your fingers will be pointing in the direction of the directional force of the magnetic lines of force. When thinking of conventional current flow, the same would apply for the right hand.



If you place your left hand on the wire with your thumb pointing in the direction of electron flow, your fingers will be pointing in the direction of the directional force of the magnetic lines of force. When thinking of conventional current flow, the same would apply for the right hand.

Figure 1–7 Lines of force forming around a conductor. Place your left hand, with thumb extended, around the coil with your fingers pointing in the direction of the electron flow through the coil. Your thumb will point to the north pole of the magnetic field.



Place your left hand, with thumb extended, around the coil with your fingers pointing in the direction of the electron flow through the coil. Your thumb will point to the north pole of the magnetic field.

Figure 1–8 Magnetic field around a coil.

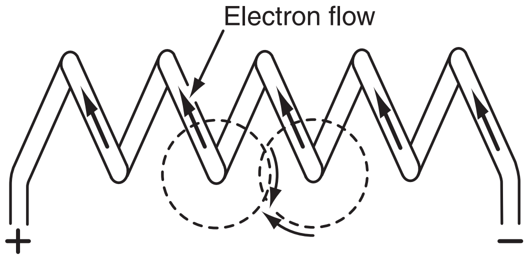


Figure 1–9 Magnetic lines of force cannot cross.

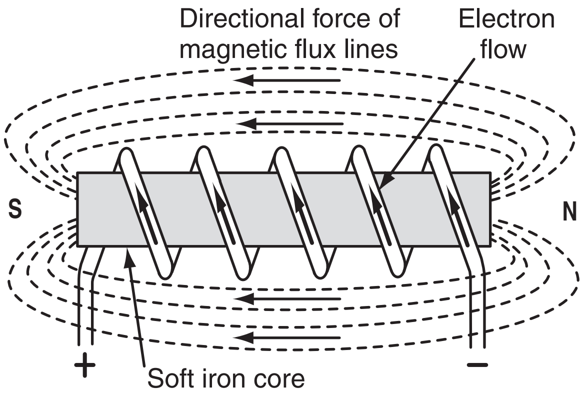


Figure 1–10 Electromagnet.

of the coil and more lines of force develop (Figure 1–10). If the core is placed toward one end of the coil (Figure 1–11), the lines of force exert a strong force on it to move it toward the center so that they can follow a shorter path. If the core is movable, it will move to the center of the coil. A coil around an off-center, movable, permeable core is a **solenoid.** A spring is usually used to hold the core off center. When the current flow is switched on to create the electromagnet, the magnetic field is stronger than the spring tension and will overcome the spring tension in order to move the iron core. This solenoid can be used to do physical work such as to engage a starter drive to a flywheel or to lock or unlock a door. But for most subjects to which this textbook pertains, there will be a valve attached to the movable iron core. This solenoid-operated valve may be spring loaded normally closed (N/C) and open when electrically energized, or it may be spring loaded normally open (N/O) and close when electrically energized.

Motors

In an electric motor, current is passed through a conductor that is looped around the **armature** core (Figure 1–12). The conductor loops are placed in grooves along the length of the core. The core is made of laminated discs of permeable, soft iron that are pressed on the armature shaft. The soft iron core causes the magnetic field that forms around the conductor to be stronger due to its permeability. There are several conductor loops on the armature, but only the loop that is nearest the center of the field poles has current passing through it. The loops are positioned so that when one side of a loop is centered on one field pole, its other side is centered on the other field pole.

The field poles are either permanent magnets or pieces of soft iron that serve as the core of an electromagnet. If electromagnets are used, an

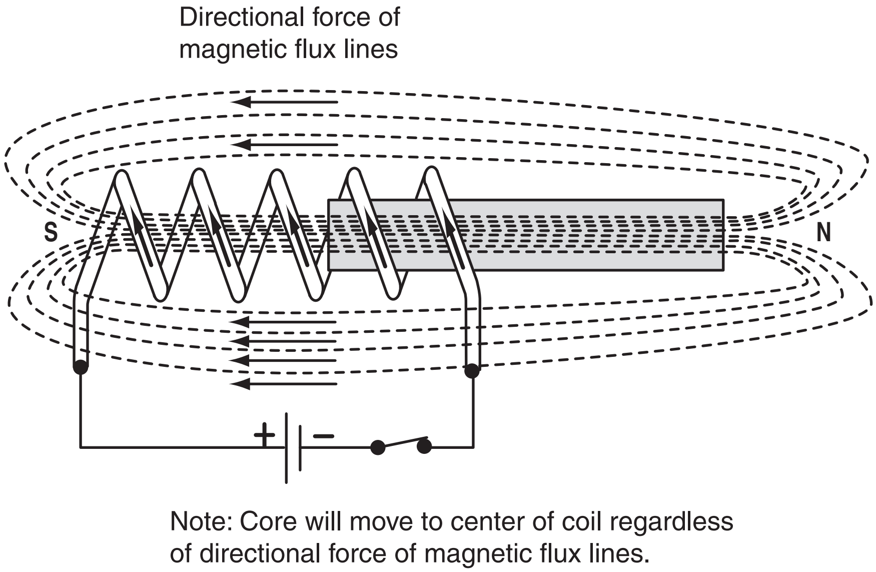

Directional force of magnetic flux lines
S
N
+
−
Note: Core will move to center of coil regardless of directional force of magnetic flux lines.

Figure 1–11 Solenoid.

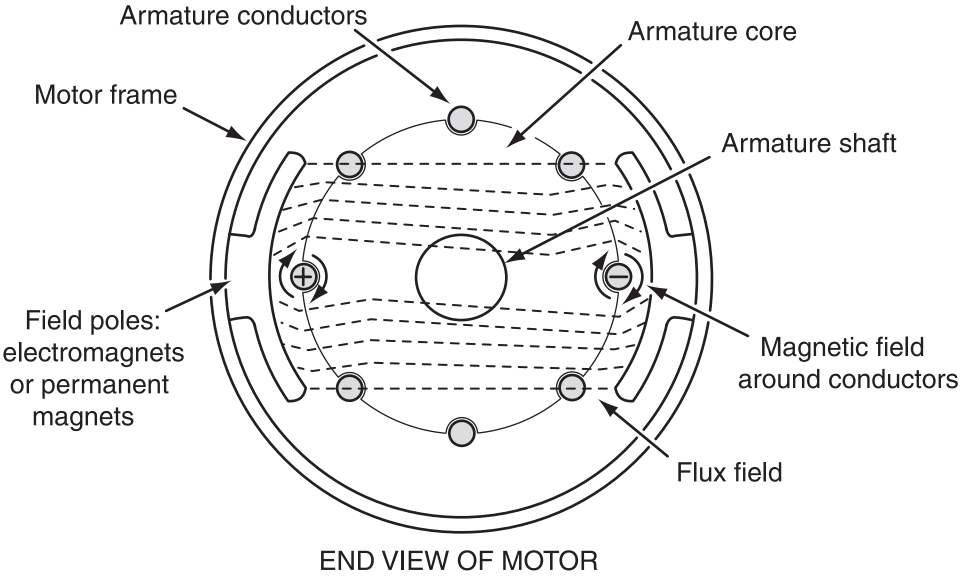


Figure 1–12 Electric motor.

additional conductor (not shown in Figure 1–12) is wound around each field pole, and current is passed through these field coils to produce a magnetic field between the field poles. The motor frame that the poles are mounted on acts as the magnet body.

Looking at the armature conductor near the north field pole in Figure 1–12, you see that its magnetic field extends out of the armature core and that it has a clockwise force. The magnetic field between the field poles has a directional force from north pole to south pole. At the top of the armature conductor, the field it has produced has a directional force in the same direction as that of the lines of force between the field poles. The lines of force in this area are compatible, but combining these two fields in the same area produces a high-density field. Remember that magnetic lines of force resist being close together.

At the bottom of the armature conductor, the lines of force formed around it have a directional force opposite to those from the north field pole. The lines of force will not cross each other, so some lines from the field pole distort and go up and over the conductor into the already dense portion of the field above the conductor, and some just cease to exist. This produces a high-density field above the conductor and a low-density field below it. The difference in density is similar to a difference in pressure. This produces a downward force on the conductor.

The other side of the armature loop, on the other side of the armature, is the same except that the current is now traveling the opposite way. The loop makes a U-shaped bend at the end of the armature. The magnetic field around this part of the conductor has a counterclockwise force. Here, the lines of force around the conductor are compatible with those between the field poles under the conductor, but they try to cross at the top. This produces an upward force on this side of the armature loop. The armature rotates counterclockwise. To change the direction in which the armature turns, either change the direction that current flows through the armature conductors or change the polarity of the field poles.

Magnetic Induction

Passing voltage through a wire causes a magnetic field to form around the wire. However, if lines of force can be formed around a conductor, a voltage is produced in the wire and current starts to flow. This assumes, of course, that the wire is part of a complete circuit. Lines of force can be made to wrap around a conductor by passing a conductor through a magnetic field (Figure 1–13). This phenomenon occurs because of characteristic 6. As the conductor passes through the magnetic field, it cuts each line of force. Because the lines of force resist being cut, they first wrap around the conductor, much like a blade of grass would if struck by a stick (Figure 1–14). This principle is used in generators to produce voltage

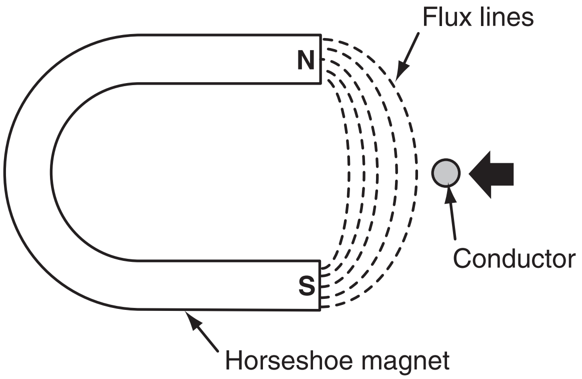


Figure 1–13 Magnetic induction.

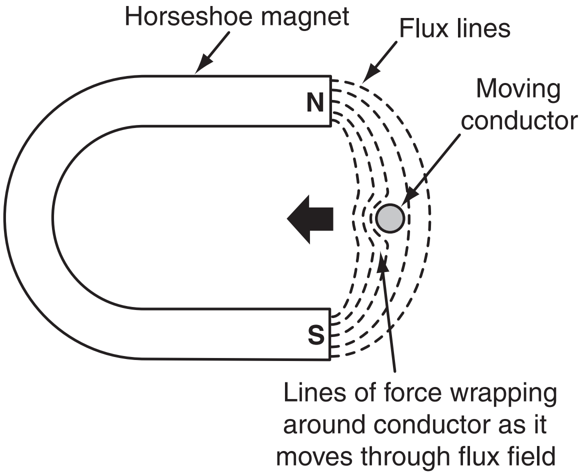

Horseshoe magnet
Flux lines
Moving conductor
N
S
Lines of force wrapping around conductor as it moves through flux field

Figure 1–14 Cutting lines of force.

and current flow. The principle will work regardless of whether:

- the conductor is moved through a stationary magnetic field, as in a DC generator,
- a magnetic field is moved past stationary conductors, as in an AC generator,
- the lines of force in an electromagnetic field are moved by having the circuit producing the magnetic field turned on and off, as in an ignition coil.

Note that in each case, movement of either the lines of force or the conductor is needed. A magnetic field around a conductor where both are steady state will not produce voltage. The amount of voltage and current produced by magnetic induction depends on four factors:

1. The strength of the magnetic field (how many lines of force there are to cut). A tiny amount of voltage is induced in the wire by each line of force that is cut.
2. The number of conductors cutting the line of force. Winding the conductor into a coil and passing one side of the coil through the magnetic field cuts each line of force as many times as there are loops in the coil.
3. How fast and how many times the conductors pass through the magnetic field.
4. The angle between the lines of force and the conductor's approach to them.

Amperage

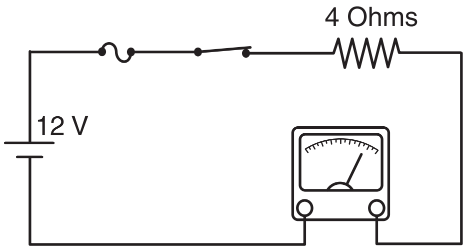
Amperage is a measure of the amount of current flowing in a circuit. One **ampere** (amp) equals 6,250,000,000,000,000,000 (6.25 billion billion) electrons moving past a given point in a circuit per second. This is often expressed as one *coulomb.*

Voltage

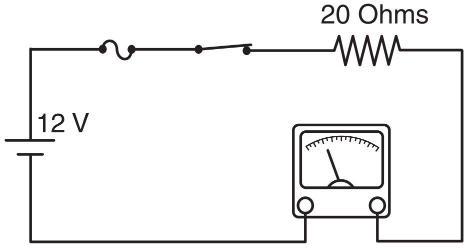
A **volt** is a measure of the force or pressure that causes current to flow; it is often referred to as **voltage.** The difference in potential is voltage. The most common ways of producing voltage are chemically, as in a battery, or by magnetic induction, as in a generator. A more accurate but less used name is **electromotive force.** Note that volts are what drive the electrons through the circuit; voltage is the measurement of that force. Similarly, **amps** are the number of electrons moving; amperage is the measurement of that number.

Resistance

The fact that voltage is required to push current through a circuit suggests that the circuit offers resistance. In other words, you do not have to push something unless it resists moving. Resistance limits the amount of amperage that flows through a circuit (Figure 1–15). The unit of measurement of resistance to flow is an **ohm.** If a circuit without enough resistance is connected across a reliable voltage source, wires or some other component in the circuit will be damaged by heat because too much current flows.



Low resistance allows more current to flow.



Higher resistance allows less current to flow.

Figure 1–15 Resistance versus current flow.

As mentioned, a bond exists between an electron and the protons in the nucleus of an atom. That bond must be broken for the electron to be freed so that it can move to another atom. Breaking that bond and moving the electron amount to doing work. Doing that work represents a form of resistance to current flow. This resistance varies from one conductive material to another, depending on the atomic structure of the material. For example, lead has more resistance than iron, and iron has more resistance than copper. It also varies with the temperature of the conductor. Loose or dirty connections in a circuit also offer resistance to current flow. Using current flow to do work (to create heat, light, or a magnetic field to move something) also amounts to resistance to current flow. There are five things that will influence resistance within a wire and/or circuit:

- *Atomic structure* of the material—for example, copper wiring versus aluminum wiring.
- *Wire gauge*—a smaller gauge of wire (higher number) increases circuit resistance.
- *Wire length*—as the wire's length is increased, so is its resistance increased.
- *Temperature*—as the temperature of a conductor increases, the resistance also increases.
- *Physical condition*—cuts, nicks, corrosion, and other deficient physical aspects of a conductor, connector, or load will increase the resistance of the circuit, thus creating excessive voltage drop within the circuit, resulting in reduced current flow.

Sometimes students get confused between voltage and amperage while doing tests on electrical systems. Review these definitions and consider the influence that voltage and amperage have on a circuit. It might also help to remember that voltage can be present in a circuit without current flowing. However, current cannot flow unless voltage is present.

Voltage Drop

When current is flowing through a circuit, voltage is lost, or used up, by being converted to some other energy form (heat, light, or magnetism). This loss of voltage is referred to as **voltage drop.** Every part of a circuit offers some resistance, even the wires, although the resistance in the wires should be very low (Figure 1–16). The voltage drop in each part of the circuit is proportional to the resistance in that part of the circuit. *The total voltage dropped in a circuit must equal the source voltage.* In other words, all of the voltage applied to a circuit must be converted to another energy form within the circuit. If excessive voltage drop occurs somewhere in a circuit due to unwanted resistance, the amperage flowing in the circuit will be reduced. This also reduces the voltage drop across the intended load component in that excessive voltage drop is occurring elsewhere in the circuit. This reduces the load component's ability to function properly. Many good computers have been replaced simply because of problems involving excessive voltage drop in the power and ground circuits that are used to power up the computer.

It should be stressed that, in order for voltage to be dropped or used up, current must be flowing in the circuit. If current is not flowing in the circuit (as in the case of a burned fuse or other open), voltage will not be dropped, but rather source voltage will be present regardless of resistance all the way from the battery to the positive side of the open, and a ground measurement of zero volts will be present on the ground side of the open as well.

Ohm's Law

Ohm's law defines a relationship between amperage, voltage, and resistance. Ohm's law says that it takes 1 volt (V) to push 1 amp (A) through 1 ohm (Ω) of resistance. Ohm's law can be expressed in one of three simple mathematical equations:

$$E = I \times R$$
$$I = E/R$$
$$R = E/I$$

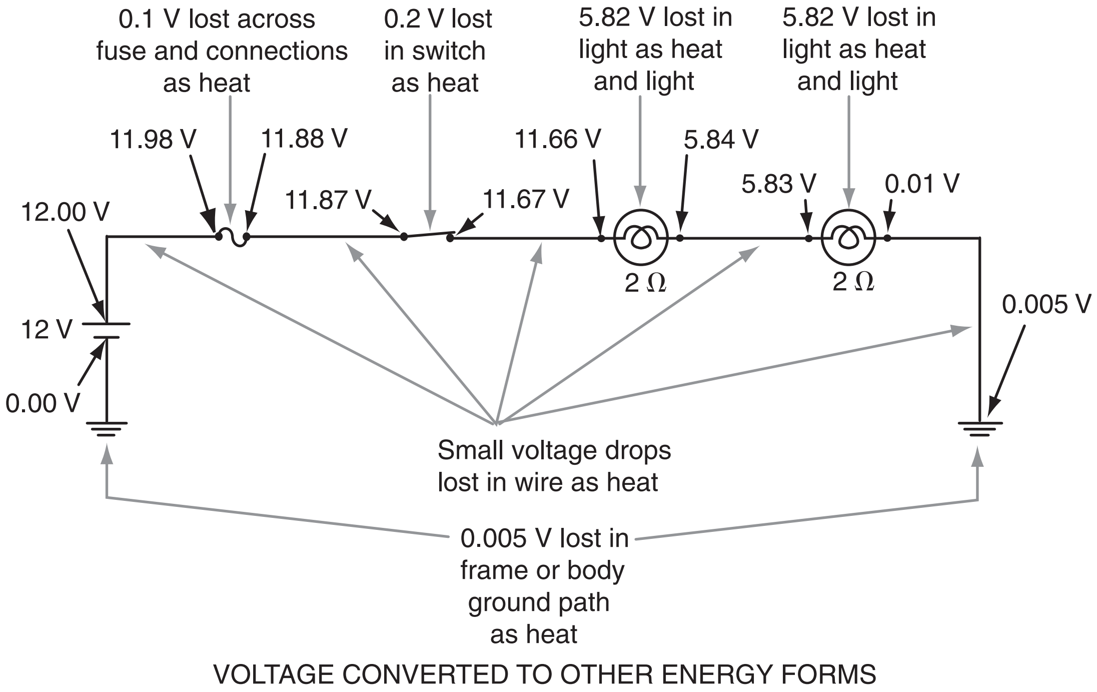

0.1 V lost across fuse and connections as heat
0.2 V lost in switch as heat
5.82 V lost in light as heat and light
5.82 V lost in light as heat and light
11.98 V
11.88 V
11.87 V
11.67 V
11.66 V
5.84 V
5.83 V
0.01 V
12.00 V
2 Ω
2 Ω
12 V
0.005 V
0.00 V
Small voltage drops lost in wire as heat
0.005 V lost in frame or body ground path as heat
VOLTAGE CONVERTED TO OTHER ENERGY FORMS

Figure 1–16 Voltage drop.

where: E = electromotive force or voltage
I = intensity or amperage
R = resistance or ohms

The simplest application of Ohm's law enables you to find the value of any one of the three factors—amperage, voltage, or resistance—if the other two are known. For example, if the voltage is 12 V and the resistance is 2 Ω (Figure 1–17), the current flow can be determined as follows:

$$I = E/R \text{ or}$$
$$I = 12\text{ V}/2\ \Omega = 6\text{ amps}$$

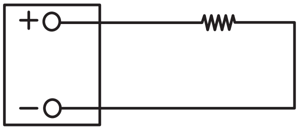


Figure 1–17 A simple series circuit.

(The Greek letter Ω, or omega, is often used as a symbol or an abbreviation for ohms, and amps is the term often used as an abbreviation for amperes.)

If the resistance is 4 Ω and the current is 1.5 amps, the voltage applied can be found by:

$$E = I \times R \text{ or}$$
$$E = 1.5\text{ amp} \times 4\ \Omega = 6\text{ V}$$

If the voltage is 12 V and the current is 3 amps, the resistance can be found by:

$$R = E/I \text{ or}$$
$$R = 12\text{ V}/3\text{ amps} = 4\ \Omega$$

Perhaps the easiest way to remember how to use these equations is to use the diagram in Figure 1–18. To find the value of the unknown factor, cover the unknown factor with your thumb and multiply or divide the other factors as their positions indicate.

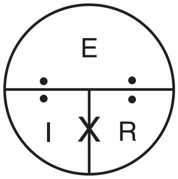


Figure 1–18 Ohm's law calculation.

There are many other applications of Ohm's law, some of which are quite complex. (A more complicated application is covered later in this chapter.) An automotive technician is rarely required to apply Ohm's law directly to find or repair an electrical problem on a vehicle. But knowing and understanding the relationship of the three factors is a must for the technician who wants to be able to diagnose and repair electrical systems effectively.

ELECTRICAL CIRCUITS

Conductors and Insulators

Previously, in discussing the electrons in the outer shell of an atom, it was said that the fewer electrons there are in the outer shell the easier it is to break them loose from the atom. If an atom has five or more electrons in its outer shell, the electrons become much more difficult to break away from the atom, and the substance made up of those atoms is a very poor conductor—so poor that it is classed as an insulator. Rubber, most plastics, glass, and ceramics are common examples of insulators. Substances with four electrons in their outer shell are poor conductors but can become good ones under certain conditions. Thus, they are called **semiconductors.** Silicon and germanium are good examples of semiconductors. (Semiconductors are covered in more detail later in this chapter.)

Conductors are substances made up of atoms with three or fewer electrons in their outer shell. These electrons are called free electrons because they are loosely held and can be freed to travel to another atom.

Circuit Design

The following three elements are essential to all electrical circuits in order to have an operating circuit:

1. *Voltage source,* such as a battery or generator, provides voltage to the power circuit.
2. *Load,* such as a motor or light, performs the function the circuit was designed to perform and also provides resistance to limit current.
3. *Circuitry or current conductors* complete the circuit between the voltage source and the load.

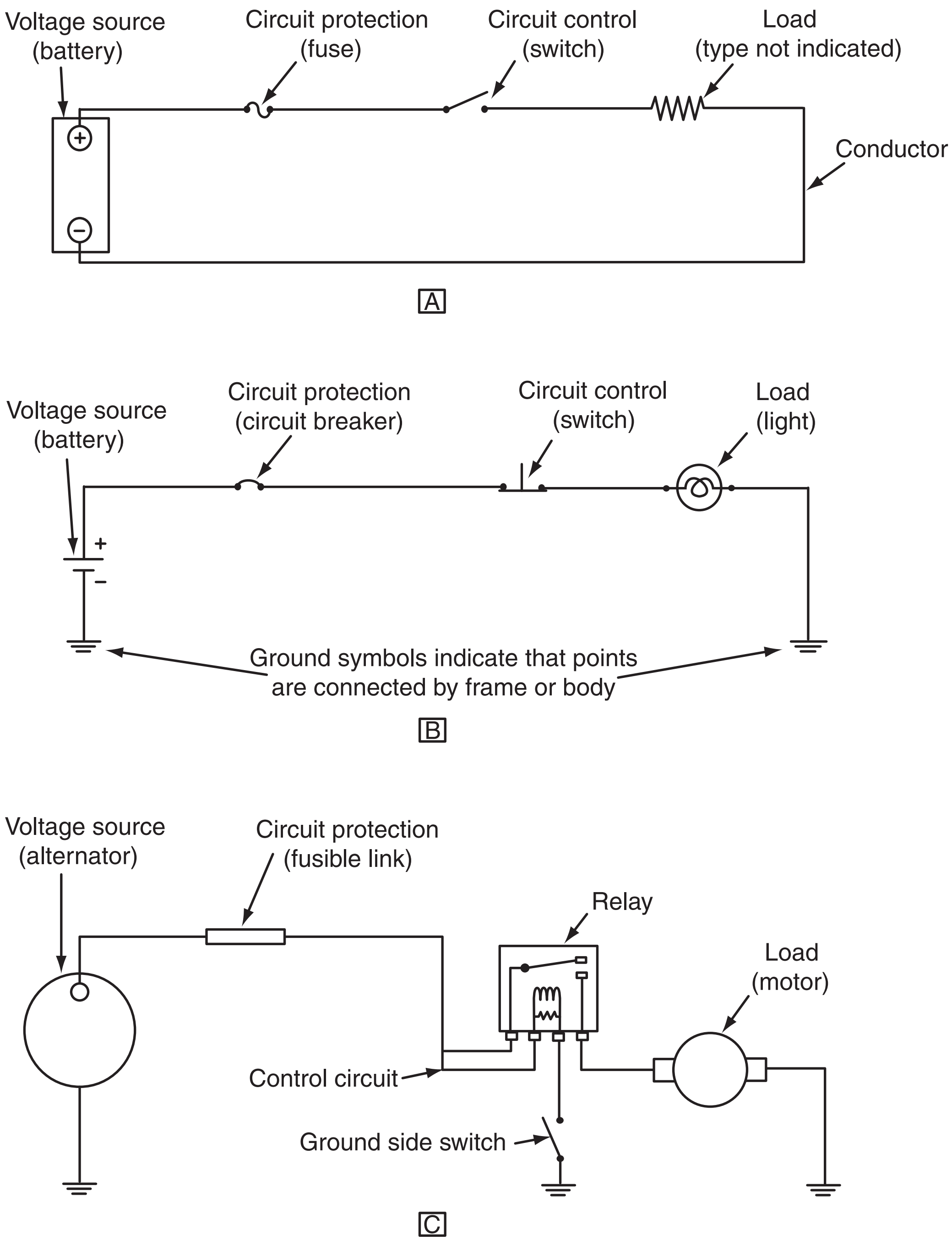
Also, most electrical circuits will have some type of component to provide each of the following functions:

- *Circuit protection,* such as a fuse or circuit breaker, serves to open the circuit in the event of excessive current flow.
- *Circuit control,* such as a switch or relay (electrically operated switch), provides the ability to control when current flows in the circuit.
- *Ground*—meaning the metal of the vehicle's body, chassis, and engine—is commonly used in place of running a copper wire on the negative side of the circuit (referred to as a negative ground).

These components are often represented by symbols as shown in Figure 1–19. You should note that any circuit protection devices, circuit control devices, and grounds constitute part of the circuitry or current conductors when used.

Circuit Types

There are two distinct types of electrical circuits, plus combinations of the two.



When control circuit is turned ON, its coil creates a magnetic field that closes the contacts which turns ON the motor.

Figure 1–19 Circuit components.

Series Circuits. In a series circuit, there is only one path for current flow and all of the current flows through every part of the circuit. Parts A and B of Figure 1–19 show simple series circuits. Even though there is only one load in each of these circuits, they qualify as series circuits because there is only one path for current flow. Figure 1–20 shows a better example of a series circuit. Not only is there just one path for current flow, there are also two loads in series with each other. When there are two or more loads in series, the current must pass through one before it can pass through the next. The characteristics of a series circuit include the following:

- Current flow is the same at all parts of the circuit.
- Resistance units are added together for total resistance.
- Current flow decreases as resistance units are added.
- All of the voltage will be used up by all of the resistance in the circuit if current is flowing. There will be no voltage left after the last resistance. Furthermore, each ohm of resistance will share equally in the voltage drop.
- An open in any part of the circuit disrupts the entire circuit.

The following problems apply Ohm's law to a series circuit. Refer to Figure 1–21, which shows a compound series circuit.

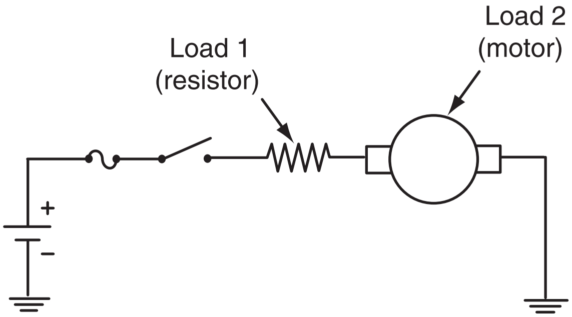


Figure 1–20 Series circuit.

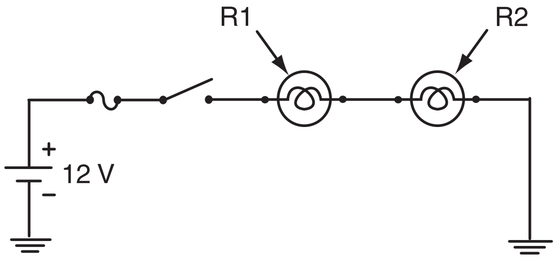


Figure 1–21 Series circuit.

Series Circuit—Problem 1. Assume that the resistance of R1 is 2 Ω and that R2 is 4 Ω; find the total current flow. In a series circuit, the resistance value of each unit of resistance can be added together because all of the current passes through each resistor.

$I = E/R$ or
$I = E/(R1 + R2)$ or
$I = 12\ V/(2\ \Omega + 4\ \Omega)$ or $12\ V/6\ \Omega = 2\ A$

Series Circuit—Problem 2. Assume the resistance values are unknown in Figure 1–21, but that the total current flow is 3 amps. To find the total resistance:

$RT = E/I$ or
$RT = 12\ V/3\ \text{amps} = 4\ \Omega$

Series Circuit—Problem 3. Find the voltage drop across R1, applying the same resistance values as in problem 1. Each ohm of resistance value shares equally in the total voltage drop in a series circuit. Therefore, how much voltage is dropped (used up) by each ohm of resistance in a circuit is also numerically equal to how many amps are flowing in the circuit. As an example, if a 12-V circuit has a resistance total of 6 Ω, we know that there the current flow is 2 amps (12/6 = 2). But the same math is also used to calculate how much voltage is dropped by each measured ohm of resistance to flow. If each ohm of resistance shares equally in the voltage drop, then 12 V divided by 6 Ω indicates that each one ohm of resistance will drop 2 V. Thus, because you are concerned with the voltage drop across R1 in Figure 1–21, multiply the resistance of R1 by the circuit's amperage.

Voltage drop across R1 = R1 × I or
2 Ω × 2 A = 4 V (voltage drop across R1)

Parallel Circuits. In a parallel circuit, the conductors split into branches with a load in each branch (Figure 1–19, Part C, and Figure 1–22). Some current will flow through each branch, with the most current flowing through the branch with the least resistance. Characteristics of a parallel circuit are:

- Current varies in each branch (unless resistance in each branch is equal).
- Total circuit current flow increases as more branches are added.
- Total circuit resistance goes down as more branches are added and will always be less than the lowest single resistance unit in the circuit.
- Source voltage is dropped across each branch.
- An open in one branch does not affect other branches.

There are three possible mathematical formulas for calculating the total resistance in a parallel circuit depending on the number of branches and how the resistances relate to each other. There is also a shortcut method that can be used in place of any of the three formulas, as also demonstrated. The following problems apply Ohm's law to a parallel circuit.

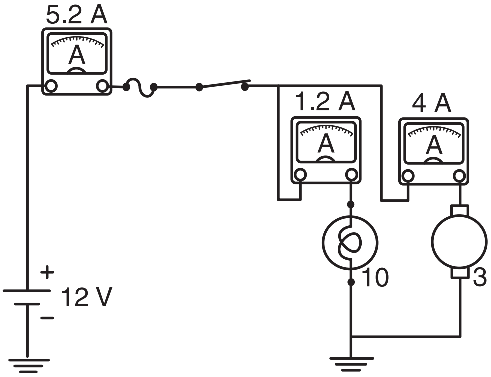


Figure 1–22 Parallel circuit.

Parallel Circuit—Problem 1: Calculating Total Resistance for a Parallel Circuit with Two Branches. The product of R1 multiplied by R2 divided by the sum of R1 plus R2 equals the resistance total (RT). This is mathematically stated as:

(R1 × R2)/(R1 + R2) = RT

In Figure 1–23, assume that R1 is 3 Ω and R2 is 4 Ω. Then calculate the resistance total as follows:

(3 Ω × 4 Ω)/(3 Ω + 4 Ω) = 12 Ω/7 Ω = 1.71 Ω

Notice that the resistance total is less than the least resistor value. This is because the total resistance to the flow of electrons is reduced as more branches that allow flow are added to the circuit.

Parallel Circuit—Problem 2: Calculating Total Resistance for a Parallel Circuit with More Than Two Branches That Have Equal Resistances. The resistance total is equal to the resistance of one branch divided by the number of branches. This is mathematically stated as:

(Resistance of one branch)/
(Number of branches) = RT

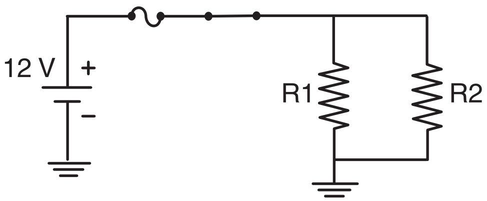


Figure 1–23 Parallel circuit with two branches.

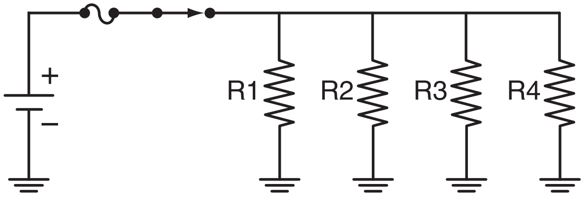


Figure 1–24 Parallel circuit with more than two branches.

In Figure 1–24, if each of the resistances in each of the four branches were 3 Ω of resistance (all are equal), the total resistance would be calculated by dividing 3 (the resistance value of one branch) by 4 (the number of branches). Thus, the resistance total would equal 0.75 Ω. Notice, again, that the resistance total is less than the least resistor value.

Parallel Circuit—Problem 3: Calculating Total Resistance for a Parallel Circuit with More Than Two Branches That Have Dissimilar Resistances. The resistance total is equal to the reciprocal of the sum of the reciprocals of each of the branch's resistance values. This is mathematically stated as:

$$1/((1/R1) + (1/R2) + (1/R3) + (1/R4) + (\text{and so on} \ldots)) = RT$$

In Figure 1–24, if R1 = 2 Ω, R2 = 3 Ω, R3 = 4 Ω, and R4 = 6 Ω, then:

$$RT = 1/((1/2) + (1/3) + (1/4) + (1/6)) \text{ or}$$
$$RT = 1/((0.5) + (0.33) + (0.25) + (0.16)) \text{ or}$$
$$RT = 1/1.24 = 0.806\ \Omega$$

Notice, again, that the resistance total is less than the least resistor value. Also, this complex mathematical formula is best done using a calculator with a memory feature. But there is an easier way.

Solving Total Resistance for a Parallel Circuit Using the Method of Assumed Voltages. This is a "cheat" method for finding the resistance total of any parallel circuit, whether it has two branches or more than two branches and whether the resistances of the branches are equal or dissimilar. Assume any convenient voltage, be it your source voltage or any other voltage that is convenient to perform the math with. Calculate the current flow for each branch at the assumed voltage. Then add up all of the current flows to find the total current flow. Then divide the assumed voltage by the total current flow to find the resistance total. Let us try applying it to Figure 1–24 using the same resistance values as used earlier.

Let us assume a source voltage of 12 V. Using Ohm's law, we can calculate the current flow easily for each branch as follows:

12 V divided by 2 Ω (R1) = 6 amps
12 V divided by 3 Ω (R2) = 4 amps
12 V divided by 4 Ω (R3) = 3 amps
12 V divided by 6 Ω (R3) = 2 amps

Then add up the current of each branch.

6 amps + 4 amps + 3 amps + 2 amps
= 15 amps

Now divide the assumed voltage by the total current.

12 V divided by 15 amps = 0.8 Ω (RT)

Now let us assume another convenient voltage of 60 V. Again, using Ohm's law, we can easily calculate the current flow for each branch as follows:

60 V divided by 2 Ω (R1) = 30 amps
60 V divided by 3 Ω (R2) = 20 amps
60 V divided by 4 Ω (R3) = 15 amps
60 V divided by 6 Ω (R3) = 10 amps

Then add up the current of each branch.

30 amps + 20 amps + 15 amps + 10 amps
= 75 amps

Now divide the assumed voltage by the total current.

60 V divided by 75 amps = 0.8 Ω (RT)

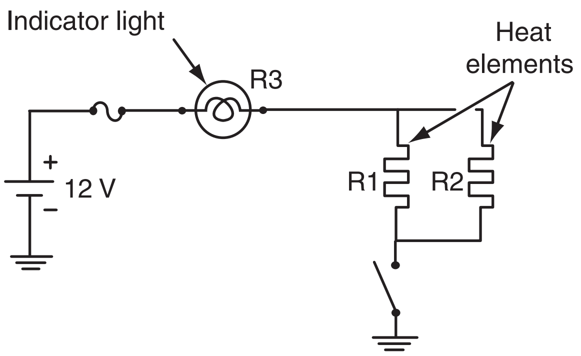


Figure 1–25 Series–parallel circuit.

Therefore, any voltage that is convenient to use with the particular resistance values will work for this shortcut method. This makes it easy enough to calculate the resistance total for any parallel circuit, thereby eliminating the need for a calculator.

Series–Parallel Circuits. Some circuits have characteristics of a series as well as those of a parallel circuit. There are two basic types of series–parallel circuits. The most common is a parallel circuit with at least one resistance unit in series with all branches (Figure 1–25). All of the current flowing through the circuit in Figure 1–25 must pass through the indicator light before it divides to go through the two heating elements, which are in parallel with each other.

To solve for current, resistance, or voltage drop values in a series–parallel circuit, you must identify how the resistance units relate to each other, then use whichever set of formulas (series circuit or parallel circuit) applies. For example:

Series–Parallel Circuit—Problem 1. In Figure 1–25, assume a resistance of 4 Ω for the indicator light (R3), 20 Ω for R1, and 30 Ω for R2. Find the total resistance for the circuit.

Branches R1 and R2 are in parallel with each other and in series with R3. First, use the product over the sum method (or the method of assumed voltages may also be used) to solve for the combined resistance of R1 and R2.

$$R = R1 \times R2/R1 + R2 \text{ or}$$
$$R = 20\ \Omega \times 30\ \Omega/20\ \Omega + 30\ \Omega$$
$$R = 600\ \Omega/50\ \Omega = 12\ \Omega$$

Now add the total resistance of R1 and R2 (12 Ω) to the resistance of R3 (4 Ω).

$$RT = R + R3 \text{ or}$$
$$12\ \Omega + 4\ \Omega = 16\ \Omega$$

Series–Parallel Circuit—Problem 2. Find the total current flow for the circuit.

$$IT = E/RT \text{ or}$$
$$IT = 12/16\ \Omega = 0.75 \text{ amp}$$

Before you can find the current flow through R1 or R2, you must find the voltage applied to R1 and R2. Remember that R3 is in series with both R1 and R2. Also remember that in a series circuit, a portion of the source voltage is dropped across each resistance unit. Therefore, because there is a voltage drop across R3, there is not a full 12 V applied to R1 and R2.

Series–Parallel Circuit—Problem 3. Find the volt drop across R3.

$$V3 = IT \times R3 \text{ or}$$
$$V3 = 0.75 \text{ amp} \times 4\ \Omega = 3 \text{ V}$$

If 3 V are dropped across R3 from a source voltage of 12 V, 9 V are applied to R1 and R2.

Series–Parallel Circuit—Problem 4. Find the current flow through:

$$R1\text{: } I1 = E/R1 \text{ or}$$
$$I1 = 9 \text{ V}/20\ \Omega = 0.45 \text{ amp}$$
$$R2\text{: } I2 = E/R2 \text{ or}$$
$$I2 = 9 \text{ V}/30\ \Omega = 0.30 \text{ amp}$$

The second type of series–parallel circuit is a parallel circuit in which at least one of the branch

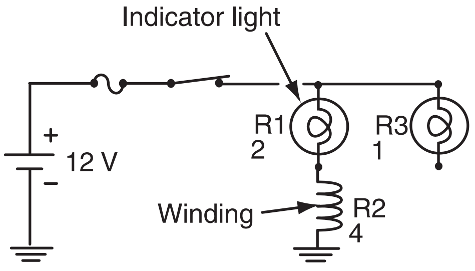


Figure 1–26 Series string in parallel.

circuits contains two or more loads in series (Figure 1–26). This type of circuit may be referred to as *series string in parallel.* Finding the total current, resistance, or voltage drop for this circuit is easy. Identify the branch, or branches, that have multiple loads in series and add up the resistances within that branch. Then treat the circuit like any other parallel circuit. When troubleshooting this kind of circuit in a vehicle, failing to recognize the branch of a circuit you are testing as having loads in series could cause confusion.

CAUTION: If you are not absolutely sure about the circuit you are testing, consult the correct wiring schematic for the vehicle.

POLARITY

Just as a magnet has polarity—a north pole and a south pole that determine the directional force of the lines of force—an electrical circuit has polarity. Instead of using north and south to identify the polarity, an electrical circuit's polarity is identified by positive and negative. An electrical circuit's polarity is determined by its power source. The best example is a battery (Figure 1–27). The side of the circuit that connects to the positive side of the battery is positive and on most vehicles is the insulated side. The voltage on this side is usually near the source voltage. Most of the voltage is dropped in the load where most of the work is done. The negative side of the circuit carries the current from the load to the negative side of the battery. There is usually very little resistance in the negative side of the circuit, and the voltage is near zero. Because this side of the circuit has the same potential as the vehicle's frame and sheet metal, this side of the circuit is not usually insulated, but rather is connected to the metal of the engine, chassis, or body and is therefore referred to as the ground side of the circuit.

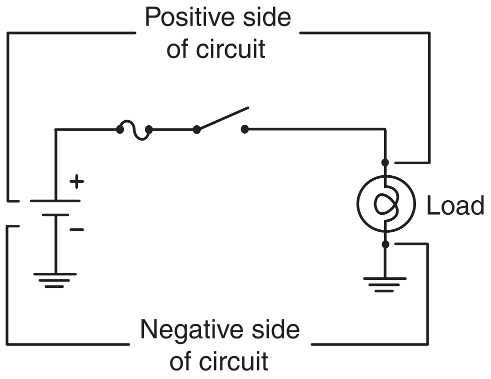


Figure 1–27 Circuit polarity.

CIRCUIT FAULTS

Three kinds of faults can occur in an electrical or electronic circuit: opens, excessive resistance, and shorts.

Opens

By far the most common fault in electrical and electronic circuits is an open circuit, or *open.* An open circuit means that there is a point in the circuit where resistance is so high that current cannot flow. An open can be the result of a broken wire, loose or dirty connection, blown fuse, or faulty component in the load device. Experienced technicians know that wires rarely break except in applications in which the wire experiences a lot of flexing. Most opens occur in connections, switches, and components. A switch in a circuit provides a way to conveniently open the circuit. Of course, when a circuit is opened deliberately, it is not a fault.

Excessive Resistance

A loose or dirty connection or a partially cut wire can cause excessive resistance in a circuit. Under these conditions, the circuit can still work, but not as well as it could, because the additional resistance reduces current flow through the circuit (Figure 1–28). Excessive resistance can also result from a faulty repair or modification of a circuit in which a wire that is too long or too small in diameter has been installed. The location of excessive resistance in a circuit can be easily found with a series of voltage drop tests, which are discussed in Chapter 6.

Shorts

A short is a fault in a circuit that causes current to bypass a portion of a circuit. The term *short* as used in electrical terminology means that the current is taking a shortcut rather than following the path it is supposed to take.

If, in an electromagnetic load, the windings overheat, resulting in melting of the material that insulates one winding from the next, the current may bypass just a few of the windings, thus reducing the circuit's intended resistance (Figure 1–29A). If only a relatively small number of the coil's loops are shorted, the increase in current flow might not be enough to further damage the circuit, although it might blow a fuse if the circuit is fuse protected. The device might even continue to work, but probably at reduced efficiency. But, if the shorted load is controlled by a computer, the resulting increase in current flow may be substantial enough to destroy the computer's ability to control this circuit (depending upon the current protection that may or may not be designed into the computer), resulting in the need to replace the computer as part of the repair. Or the current may bypass the entirety of the load, thus reducing the circuit's resistance to near zero ohms (Figure 1–29B). Also, a short may bypass a switch or relay-operated switch and thus create an "always on" condition in which the circuit cannot be properly controlled (Figure 1–29C).

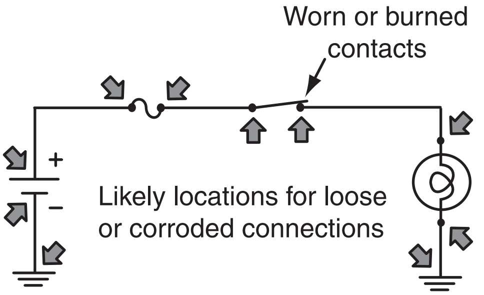


Figure 1–28 Possible locations in a circuit for an open or high resistance.

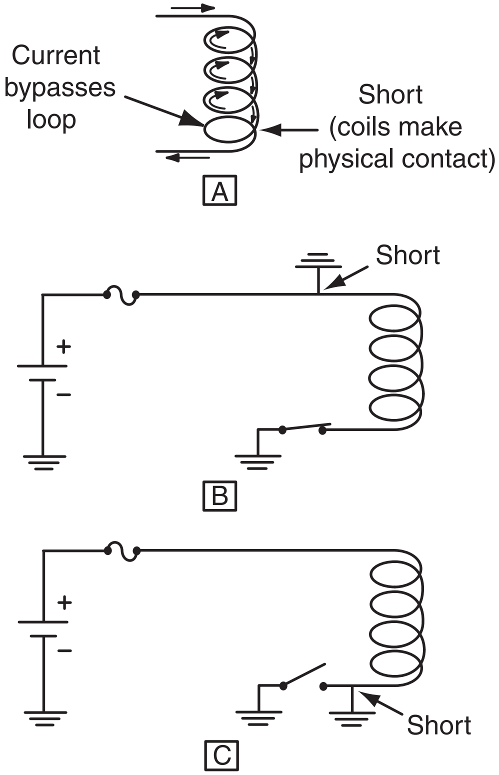


Figure 1–29 Shorts.

Short to Power. Figure 1–29B demonstrates a short to power (positive) and a short that also allows current to fully bypass the load. This would likely quickly blow the fuse due to the increased current. In this example, the circuit will not operate at all until the problem is corrected and the fuse is replaced. If an improper fuse has been installed with an amperage rating that is higher than the manufacturer-recommended amperage rating, a fire could result. ***Do not ever*** replace a fuse with one other than the fuse recommended by the manufacturer unless the manufacturer directs you to do so through a Technical Service Bulletin (TSB).

A short finder is an excellent tool for finding this type of short; it consists of a self-resetting circuit breaker that temporarily replaces the fuse and a sensitive inductive meter that can sense the pulsing of the magnetic field from the battery to the point of the short.

Short to Ground. Figure 1–29C demonstrates a short to ground (negative) and a short that also bypasses the switch that controls the load. This short would not blow the fuse but, instead, would keep the circuit energized continuously.

SEMICONDUCTORS

Semiconductors are the basis of today's *solid-state electronics,* or electronic devices such as computers and amplifiers that are able to control the most complex systems without having any moving parts. As mentioned previously in this chapter, a semiconductor is an element with four valence electrons. The two most-used semiconductor materials for solid-state components are silicon and germanium. Of these two, silicon is used much more than germanium. Therefore, most of this discussion will apply to silicon.

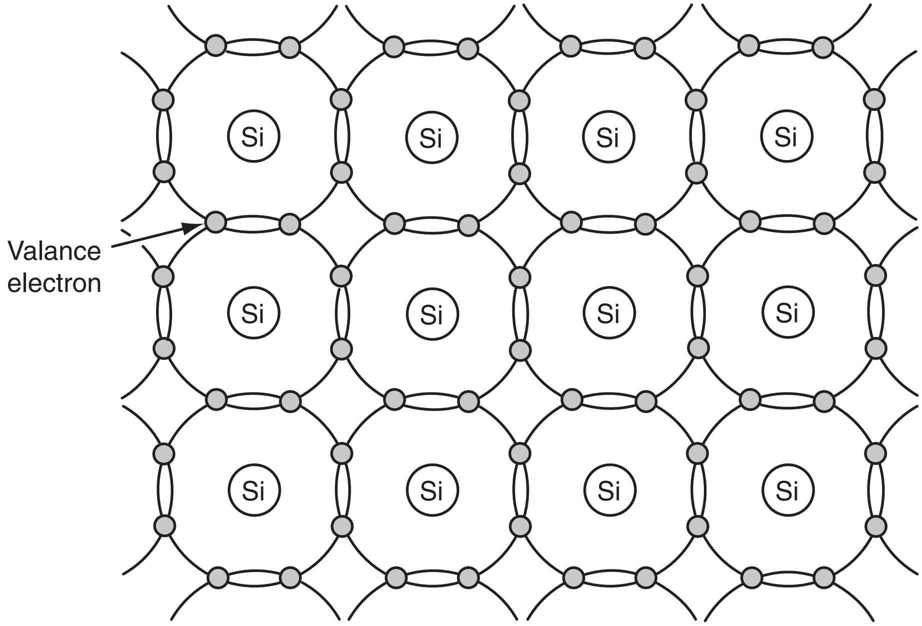
As previously stated, an atom with three or fewer electrons in its outer shell easily gives them up. If an atom has more than four but fewer than eight electrons in its outer shell, it exhibits a tendency to acquire more until it has eight. If there are seven electrons in the outer shell, the tendency to acquire another one is stronger than if there are only six. Once there are eight, it becomes very stable; in other words, it is hard to get the atom to gain or lose an electron. In a semiconductor material—for example, a silicon crystal—the atoms share valence electrons in what are called covalent bonds (Figure 1–30). Each atom positions itself so that it can share the valence electrons of neighboring atoms, giving each atom, in effect, eight valence electrons. This lattice structure is characteristic of a crystal solid and provides two useful characteristics:

1. Impurities can be added to the semiconductor material to increase its conductivity; this is called *doping.*
2. It becomes *negative temperature coefficient,* meaning that its resistance goes down as its temperature goes up. (This principle is put to use in temperature sensors, as we will see in Chapter 3.)

Doping

All of the valence electrons in a pure semiconductor material are in valence rings containing eight electrons (Figure 1–30). With this atomic structure, no electrons can be easily freed, and there are no holes to attract an electron even if some were available. The result is that this material has a high resistance to current flow. Adding very small amounts of certain other elements can greatly reduce the semiconductor's resistance. Adding trace amounts (about 1 atom of the doping element for every 100 million semiconductor atoms) of an element with either five or three valence electrons can create a flaw in some of the covalent bonds.

Adding atoms with five valence electrons (referred to as *pentavalent atoms*) such as arsenic, antimony, or phosphorus achieves a crystal structure as shown in Figure 1–31. In Figure 1–31, phosphorus is the doping element and silicon is the base semiconductor element. Four of the phosphorus atom's five valence electrons are shared in the valence rings of neighboring



Each silicon atom shares an electron with each neighboring atom.

Figure 1–30 Covalent bonds.

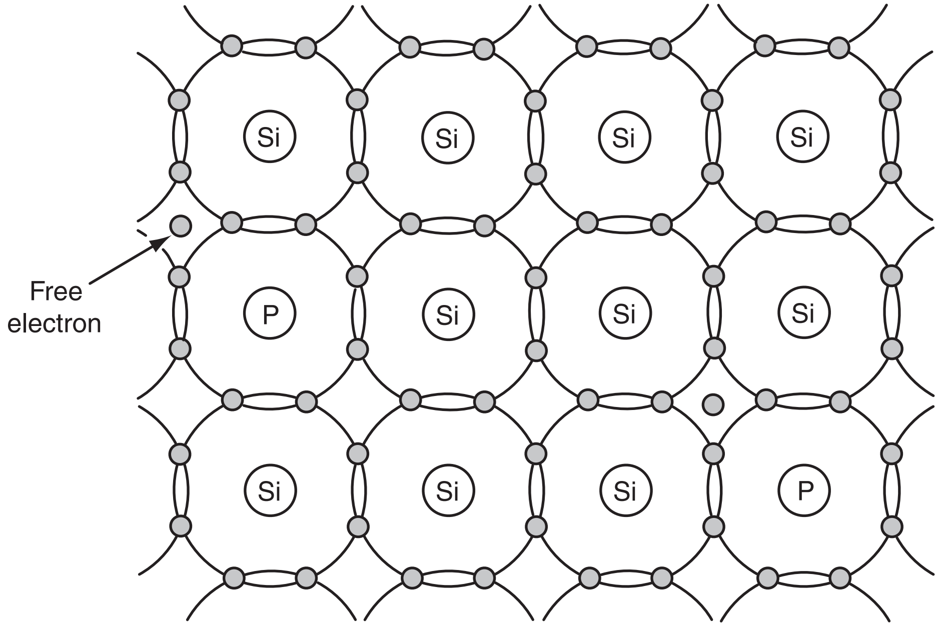


Figure 1–31 Silicon doped with phosphorus.

silicon atoms, but the fifth is not included in the covalent bonding with neighboring atoms; it is held in place only by its attraction to its parent phosphorus atom—a bond that can be broken easily. This doped semiconductor material is classified as an N-type material. Note that it does not have a negative charge because the material contains the same number of protons as electrons. It does have electrons that can be easily attracted to some other positive potential.

Adding atoms with three valence electrons (referred to as *trivalent atoms*) such as aluminum, gallium, indium, or boron achieves an atomic structure as seen in Figure 1–32. In Figure 1–32, boron is used as the doping material in a silicon crystal. The boron atom's three valence electrons are shared in the valence ring of three of the neighboring silicon atoms, but the valence ring of the fourth neighboring silicon atom is left with a hole (electron deficiency) instead of a shared electron. Remember that a valence ring of seven electrons aggressively seeks an eighth electron. In fact, the attraction to any nearby free electron is stronger than the free electron's attraction to its companion proton in the nucleus of its parent atom. Thus this material is classified as a P-type.

Doping Semiconductor Crystals

In actuality, a PN junction is not produced by placing a P- and an N-type semiconductor back to back. Rather, a single semiconductor crystal is doped on one side with the pentavalent atom's opposite sides and on the other with trivalent atoms. The center of the crystal then becomes the junction. The doping is done by first bringing the semiconductor crystal to a molten temperature. In a liquid state, the covalent bonds are broken. The desired amount of doping material is then added. As the semiconductor crystal cools, the covalent bonds redevelop with the doping atoms included.

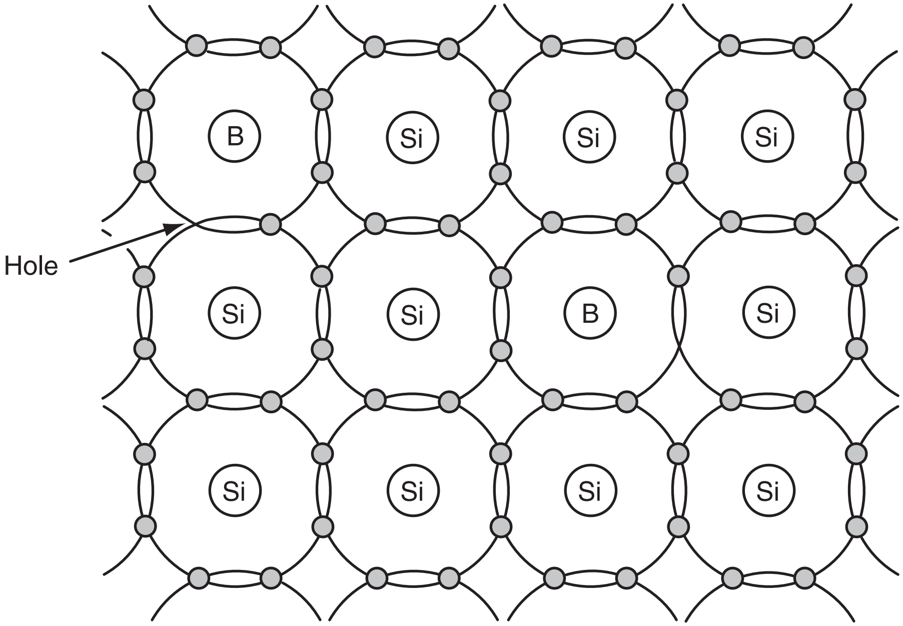
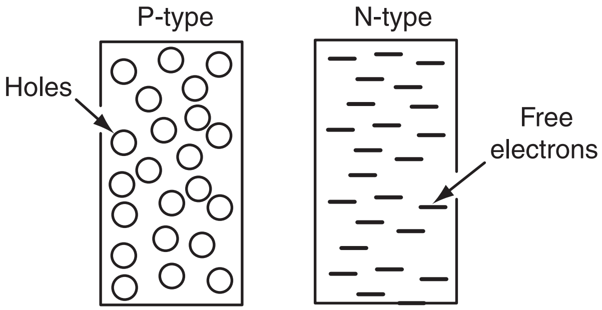


Figure 1–32 Silicon doped with boron. Note: For simplicity, only the holes and free electrons that result from the pentavalent and trivalent atoms are shown; the stable atoms are left out.



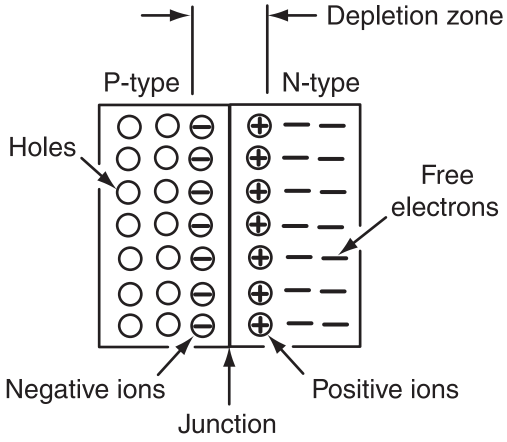
Note: For simplicity, only the holes and free electrons that result from the pentavalent and trivalent atoms are shown; the stable atoms are left out.

Figure 1–33 P-type and N-type crystals. Note: For simplicity, only the holes, free electrons, and ions are shown; the stable atoms are left out.

PN Junction

Figure 1–33 shows a P-type crystal and an N-type crystal separated from each other. Only the free electrons in the N-type and the holes (electron deficiencies) in the P-type that result from the way in which the doping atoms bond with the base semiconductor material are shown. If the P-type and the N-type are put in physical contact with each other, the free electrons near the *junction* in the N-type cross the junction and fill the first holes they come to in the seven-electron valence rings near the junction of the P-type (Figure 1–34). The junction is the area that joins the P-type and N-type. This action quickly creates a zone around the junction in which:

- There are no more free electrons in that portion of the N-type.
- There are no more free holes (electron deficiencies) in that portion of the P-type.
- The valence rings near the junction in both the N- and P-type have eight shared electrons, so they are reluctant to gain or lose any more.



Note: For simplicity, only the holes, free electrons, and ions are shown; the stable atoms are left out.

Figure 1–34 PN junction.

Another way to state the information in the preceding list is to say that there are no longer any current carriers in the zone around the junction. This zone is often referred to as the *depletion zone.* It is also sometimes referred to as a boundary layer. In addition:

- The phosphorus atoms near the junction in the N-type have each lost an electron, which makes them positive ions (the free electron that crossed the junction to fill a hole in the P-type abandoned a proton in the nucleus of the phosphorus atom).

- The boron atoms near the junction in the P-type have each gained an electron, which makes them negative ions (the electron that dropped into the valence ring around the boron atom is not matched by a proton in the nucleus of the boron atom).

The positive ions near the junction in the N-type are attracted to the free electrons that are farther from the junction, but they are more strongly repulsed by the negative ions just across the junction. Likewise, the negative ions in the P-type are attracted to the holes that are farther from the junction, but those holes are more strongly repulsed by the positive ions on the N-side of the junction. The extra electrons in the negative ion atoms are somewhat attracted to the nearby holes, but they are more strongly bound by the covalent bonding into which they have just dropped.

Keep in mind that a layer of negative ions along the junction in the P-type and a layer of positive ions along the junction of the N-type have been created. The opposing ionic charges on the two sides of the depletion zone create an electrical potential of about 0.6 V (0.3 V for germanium). This potential, often referred to as the *barrier potential,* cannot be measured directly, but its polarity prevents current from flowing across the junction unless it is overcome by a greater potential.

Conventional Current Flow versus Electron Current Flow

Before electrons were known, Benjamin Franklin surmised that current was a flow of positive charges moving from positive to negative in a circuit. Franklin's belief became so accepted that even after electrons were discovered and scientists learned that current flow consists of electrons moving from negative to positive, the old idea was hard to give up. As a result, the "idea" of positive charges moving from positive to negative is still often used. It is referred to as *conventional current flow* or less formally as *hole flow.*

The conventional current flow theory has gotten a boost in recent years because it helps explain how semiconductors work: Positively charged holes move from positive charges to negative charges as electrons move from negative charges to positive charges.

Diodes

If two of these semiconductor materials, one N-type and one P-type, are placed back to back, the simplest semiconductor device, known as a **diode,** is formed. A diode operates as an electrical one-way check valve with no moving parts; it will allow current to pass in one direction only. If a positive electrical potential is applied to the positive end and a negative electrical potential is applied to the negative end and the applied electrical pressure (voltage) is greater than 0.6 V, the applied polarity will cause the diode to gain continuity across the PN junction. In this condition the diode is said to be *forward biased* (Figure 1–35).

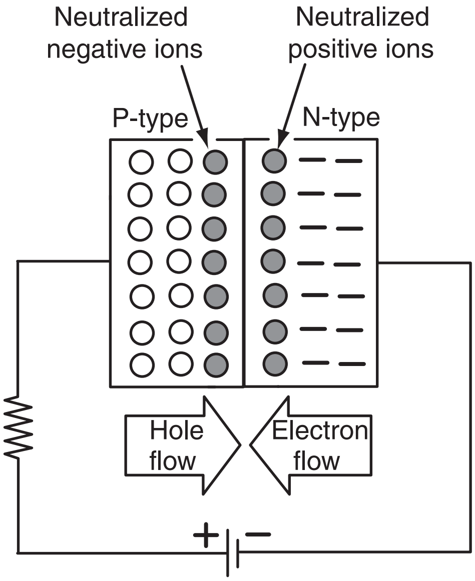


Figure 1–35 Forward bias voltage applied to a diode.

The higher negative potential introduced by the forward bias voltage at the negative side of the crystal repels the free electrons in the N-type material. They move toward the junction, canceling the charge of the positive ions. At the same time, the higher positive potential introduced by the forward bias voltage on the positive side of the crystal repels the free holes in the P-type. They move toward the junction, canceling the charge of the negative ions. With the barrier potential overcome, current easily flows across the junction, with electrons moving toward the external positive potential and holes moving toward the external negative potential. When the forward bias voltage is removed, barrier potential redevelops and the diode again presents high resistance to current flow.

If this polarity is reversed, the diode acts as an insulator. In this condition the diode is said to be *reverse biased* (Figure 1–36). If a reverse bias voltage is applied, with a negative potential applied to the P-side and a positive potential applied to the N-side, the positive potential attracts free electrons away from the junction, and the negative potential attracts holes away from the junction. This causes the depletion zone to be even wider and the resistance across the junction to increase even more. If the reverse bias voltage goes high enough—that is, above 50 V for most rectifier diodes (those designed to conduct enough current to do work, and the most common type)—current will flow. It will rise quickly, and in most cases the diode will be damaged. This is called the *breakdown voltage.*

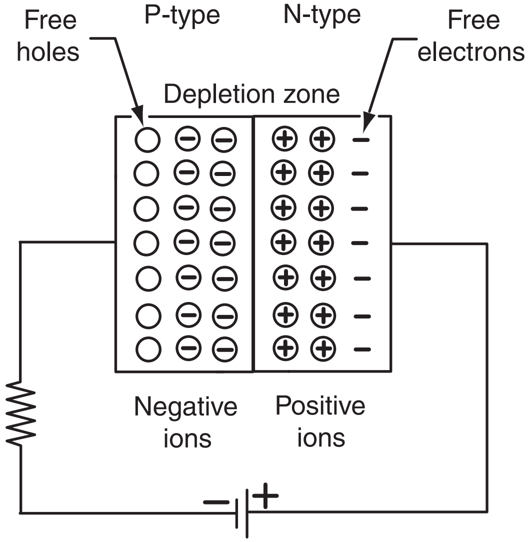


Figure 1–36 Reverse bias voltage applied to a diode.

Diodes can be designed to carry various amounts of current. For example, the diodes in an alternator are designed to carry a substantial amount of current; at the other extreme, the miniaturized diodes contained within an IC chip can only carry very small amounts of current and yet will still function electrically as diodes. The amount of current that a diode (or any other type of semiconductor with one or more PN junctions) can safely handle is determined by such things as its physical size, the type of semiconductor and doping material used, its heat dissipating ability, and the surrounding temperature. If the circuit through which forward bias voltage is applied does not have enough resistance to limit current flow to what the semiconductor can tolerate, it will overheat and the junction will be permanently damaged (open or shorted).

Diode Symbols

The most commonly used symbol to represent a diode is an arrow with a bar at the point (Figure 1–37A). The point always indicates the direction of current flow using conventional theory. With electron theory the flow is opposite the direction that the arrow is pointing. The arrow side of the symbol also indicates the P-side of the diode, often referred to as the *anode.* The bar at the end of the arrow's point represents the N-side and is often called the *cathode.* Thus, a better way to look at a diode symbol within an electrical schematic and know how it affects the circuit is to do as follows: If the polarity applied to the diode is more positive at the anode end (or more negative at the cathode end), it will operate as a conductor; likewise, if the polarity applied to the diode is

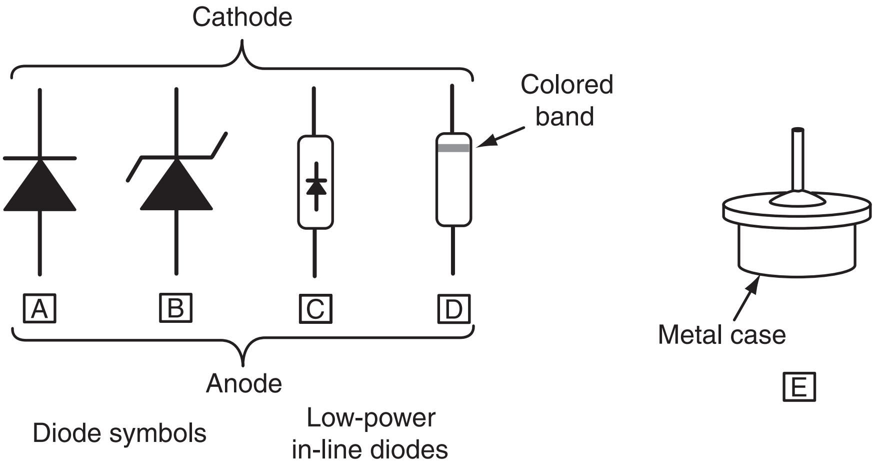


Figure 1–37 Diodes.

more negative at the anode end (or more positive at the cathode end), it will operate as an insulator. Figure 1–37B shows a modified diode symbol that represents a zener diode.

On actual diodes, the diode symbol can be printed on one side to indicate the anode and cathode ends (Figure 1–37C), or a colored band can be used instead of the symbol (Figure 1–37D). In this case the colored band will be nearer to the cathode end. Figure 1–37E shows a power diode. A power diode is one large enough to conduct larger amounts of current to power a working device. It will be housed in a metal case, which can serve as either the anode or the cathode connector and will also dissipate heat away from the semiconductor crystals inside. The polarity of a power diode can be indicated by markings or, in the case of specific part number applications such as for an alternator, it may be sized or shaped so that it can be installed only one way.

Zener Diode

A zener diode is one in which the crystals are more heavily doped. Because of this the depletion zone is much narrower, and its barrier voltage becomes very intense when a reverse bias voltage is applied. At a given level of intensity, the barrier voltage pulls electrons out of normally stable valence rings, creating free electrons. When this occurs, current flows across the diode in a reverse direction without damaging the diode. The breakdown voltage at which this occurs can be controlled by the amount of doping material added in the manufacturing process. Zener diodes are often used in voltage-regulating circuits.

Diode Applications

The best-known application of diodes in the automobile is their use to *rectify AC voltage to DC voltage* within the alternator. The winding in Figure 1–38 represents one of the stator windings within the alternator. The alternator's rotating electromagnetic field windings induce an AC voltage pulse within each stator winding with each rotation. For 180 degrees of the field winding's rotation a positive voltage pulse is induced in the stator winding (Figure 1–39), and during the following 180 degrees of the field winding's rotation

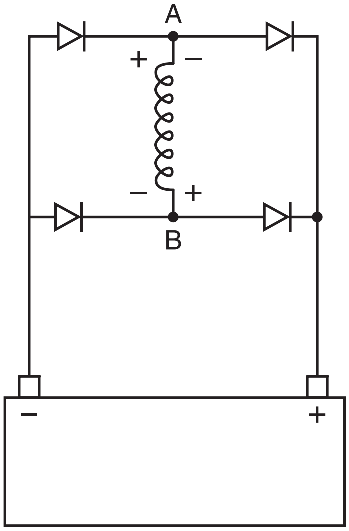


Figure 1–38 Full wave AC-to-DC rectification.

a negative voltage pulse is induced in the stator winding. In Figure 1–38, when Point A is positive and Point B is negative, the positive charge at Point A is blocked by the diode on the left and is conducted by the diode on the right, and the negative charge at Point B is blocked by the diode on the right and conducted by the diode on the left. After a further 180 degrees of alternator rotation, when Point A is negative and Point B is positive, the negative charge at Point A is blocked by the diode on the right and is conducted by the diode on the left, and the positive charge at Point B is blocked by the diode on the left and conducted by the diode on the right. Thus, both AC voltage pulses are applied to the vehicle's battery as positive DC voltage pulses (Figure 1–40) because the negative AC voltage pulse has now been flipped upright as a positive voltage pulse. This is known as full wave AC-to-DC rectification. (Half wave rectification would simply leave the negative voltage pulse unused, or wasted, and would only make use of the positive voltage pulses, whereas full wave rectification uses both the positive and negative pulses by turning the negative pulses into positive ones.)

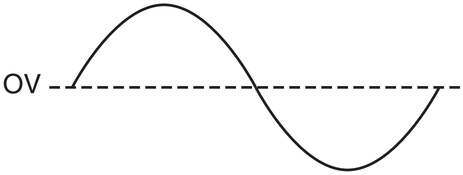


Figure 1–39 AC voltage induced in a stator winding with one rotation of the alternator.

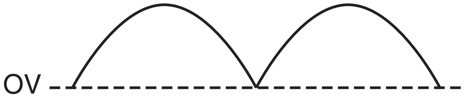


Figure 1–40 Full wave rectification of the AC voltage to a DC voltage.

However, because the alternator actually contains three stator windings into which the rotating field windings induce voltage pulses, one immediately after another, initially three sets of these positive and negative voltage pulses are induced into the stator windings for each rotation of the field windings (Figure 1–41). After the diodes in the rectifier bridge fully rectify the negative voltage pulses into positive voltage pulses (Figure 1–42), the effective voltage applied to the

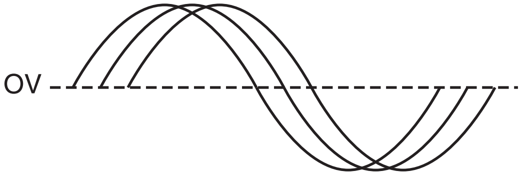


Figure 1–41 AC voltage pulses induced in the three stator windings of an alternator.

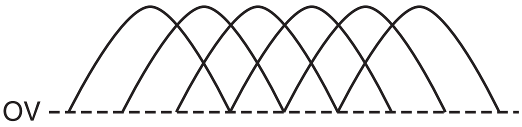


Figure 1–42 Voltage pulses of three stator windings, all rectified to positive voltage pulses.

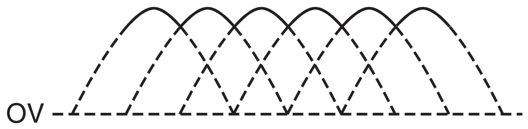


Figure 1–43 The resulting DC voltage after AC-to-DC rectification as it is applied from the alternator's output terminal to the battery.

battery is actually a relatively stable DC voltage that only varies slightly around 14.2 V, as shown by the solid waveform depicted in Figure 1–43. The slight variation in this waveform is known as alternator AC ripple and is best measured at the alternator output terminal with an AC voltmeter. If a diode is open or shorted, or if a stator winding is open, the amplitude (difference between the high and the low voltage) of this signal will be too great. Excessive AC ripple causes problems with a computer's internal and external communication and can be a reason why good computers are unnecessarily replaced.

Another automotive application of diodes is to *control current flow paths in circuits that share a common load component*. An example of this is shown in Figure 1–44. The driver's door switch closes when the door is opened to alert the module that it should remove the motorized shoulder belt from off the driver. Similarly, the passenger's door switch closes when the passenger door is opened to alert the module that it should remove the motorized shoulder belt from off the passenger. However, either switch will ground the "door ajar" lamp in the instrument cluster to illuminate it. Without diodes, opening one door would cause a ground signal that would back up through the other door's circuit and would cause the module to believe falsely that both doors had been opened. By using diodes within the "door ajar" lamp assembly, the circuits can be effectively isolated from each other even though either circuit can illuminate the warning lamp.

A third automotive application that uses diodes is *voltage spike suppression,* though the diode is only one of three methods used. Figure 1–45 shows a winding that represents an electromagnetic load that is switched on and off. When current flow is switched on, current ramps up relatively slowly to the fully saturated level as dictated by Ohm's law, just as turning on a water valve will only *allow* the water pressure that is present to begin pushing water through the pipe. Therefore, the resulting electromagnetic field does not build quickly enough to induce a voltage spike within the electromagnetic winding as it expands across it. However, when the driver (transistor within the computer that controls the

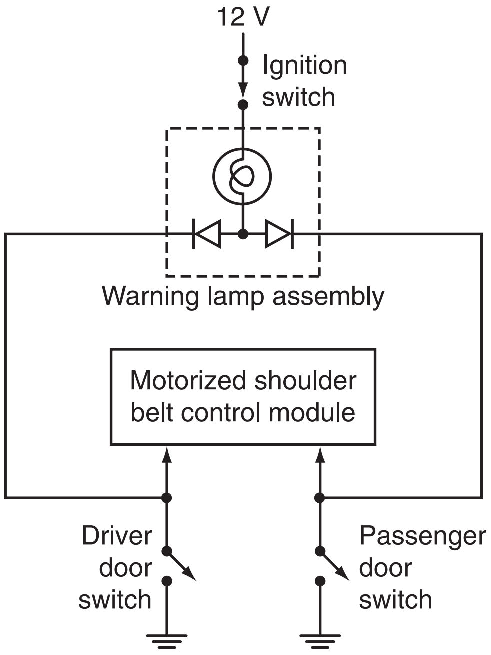


Figure 1–44 Diodes used to control current flow paths in circuits that share a common load.

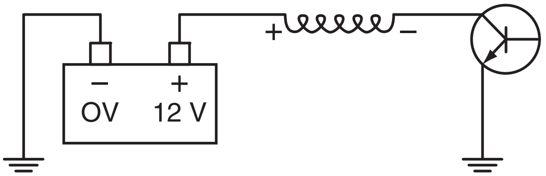


Figure 1–45 Electromagnetic load controlled by a computer's transistor.

load) is turned off, current collapses very quickly, just as when you shut off a valve in a water pipe, the valve forcibly and immediately stops the flow of water. In an electrical circuit, when the driver is turned off, the current stops rapidly. As a result, the electromagnetic field collapses so rapidly across its own winding that it induces a voltage potential within the winding of the opposite polarity of the originally applied voltage. In many circuits, this voltage spike is suppressed at the actuator's winding in order to keep it from reaching and damaging the on-board computers.

In order to suppress the voltage spike created each time an electromagnetic load is de-energized, a circuit must be placed in parallel to the electromagnetic load that will allow the voltage potential to dissipate. The voltage potential, of course, simply consists of an excess of electrons at the negative end of the winding and a deficiency of electrons at the positive end. If another wire were simply connected between the two ends of the winding, the voltage spike would be allowed to dissipate each time it was induced in the winding. However, this also creates another problem in that the wire also constitutes a short that bypasses the load device during normal operation. So a component must be added to this parallel circuit to restrict the current that could bypass the load during normal operation while allowing the voltage spike that is induced in the winding each time it is de-energized to dissipate.

Three different methods are commonly used. If a diode is placed in this parallel circuit with the cathode end placed toward the positive side of the circuit (Figure 1–46), the diode blocks the current flow during normal operation, thus preventing any current from bypassing the load, but will allow the voltage spike to dissipate through the diode each time the circuit is de-energized due to the reversed polarity of the voltage spike. This is commonly called a **clamping diode.** Another method is to place a calculated resistance in the parallel circuit that allows a minimal amount of current flow during normal operation but has a resistance value that is low enough to allow the bulk of the voltage spike to dissipate. The diode or resistor is commonly seen in electrical schematics in spike suppression relays. A third method is to place a capacitor in the parallel circuit, which temporarily absorbs the voltage spike potential, such as in many Ford idle air control solenoids.

There are many other applications of diodes in today's vehicles, including solid-state voltage regulators and electronic modules. As the simplest semiconductor, the diode is a basic but effective building block of today's electronic systems.

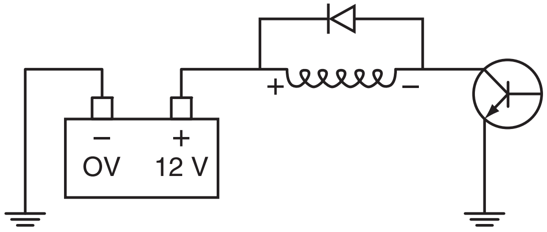


Figure 1–46 A diode used to suppress the voltage spike, known as a spike diode or a clamping diode.

Transistors

The **transistor,** probably more than any other single component, has made possible the world of modern electronics. A transistor operates as an electrical switch with no moving parts. Transistors most commonly used in automotive applications are called *bipolar transistors* because they use two polarities—electrons and holes (electron deficiencies). Bipolar transistors contain three doped semiconductor crystal layers called the *collector,* the *base,* and the *emitter* (Figure 1–47).

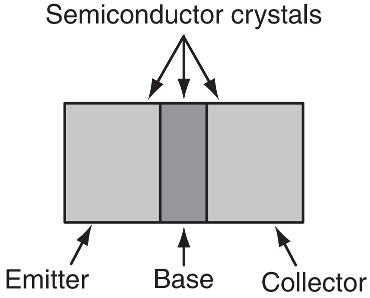


Figure 1–47 Components of a bipolar transistor.

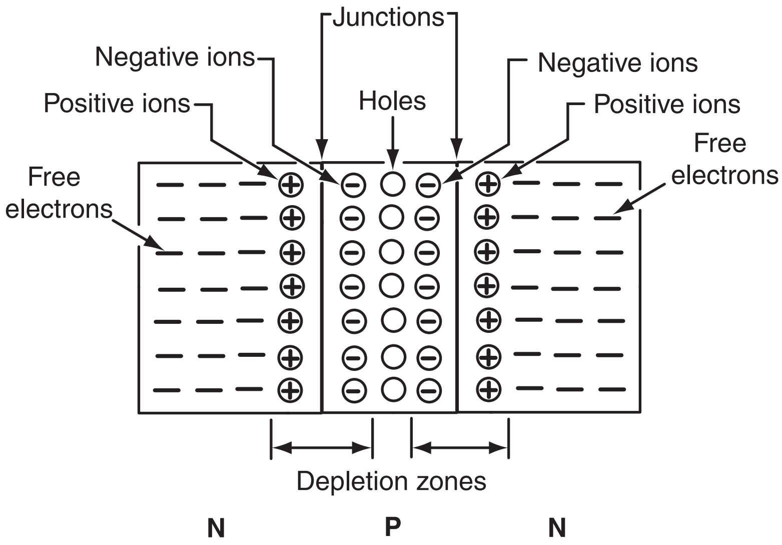


Figure 1–48 Unbiased transistor.

The base is always sandwiched between the emitter and the collector. The major difference between a diode and a transistor is that a transistor has two PN junctions instead of one. In effect, a transistor is two diodes placed back to back. They can be arranged to have a P-type emitter and collector with an N-type base (a PNP transistor) or an N-type emitter and collector with a P-type base (an NPN transistor). PNP transistors are used for positive side switching and NPN transistors are used for negative (ground) side switching. Because automotive computers control most automotive load components by switching the ground side, the NPN is the more common transistor; it is discussed in the following paragraphs.

In an NPN transistor, the emitter is heavily doped with pentavalent atoms; its function is to emit free electrons into the base. The base is lightly doped with trivalent atoms and is physically much thinner than the other sections. The collector is slightly less doped than the emitter but is more doped than the base.

Recalling the discussion of the PN junction, you know that a barrier potential forms at each junction (Figure 1–48). An NPN transistor can be forward biased by applying an external voltage of at least 0.6 V to both the base and the emitter, with the positive potential to the base (the P portion) and the negative potential to the emitter. With a positive potential also applied to the collector, the diode will gain continuity through it from the collector to the emitter, thereby completing the circuit for whatever load is connected to the collector (Figure 1–49).

Because the base is lightly doped, it does not have many holes into which the free electrons can drop. The holes that do exist are quickly filled. Because the base crystal is thin and has so few holes for free electrons to drop into, the majority of the free electrons coming from the emitter cross the base into the collector. The collector readily accepts them because the free electrons in the collector are attracted to the positive potential at the collector electrode and leave behind a lot of positive ions. Because there are so few holes that allow free electrons to drop into valence rings in the base, the current in the base-emitter circuit is quite small compared to the current in the collector-emitter circuit.

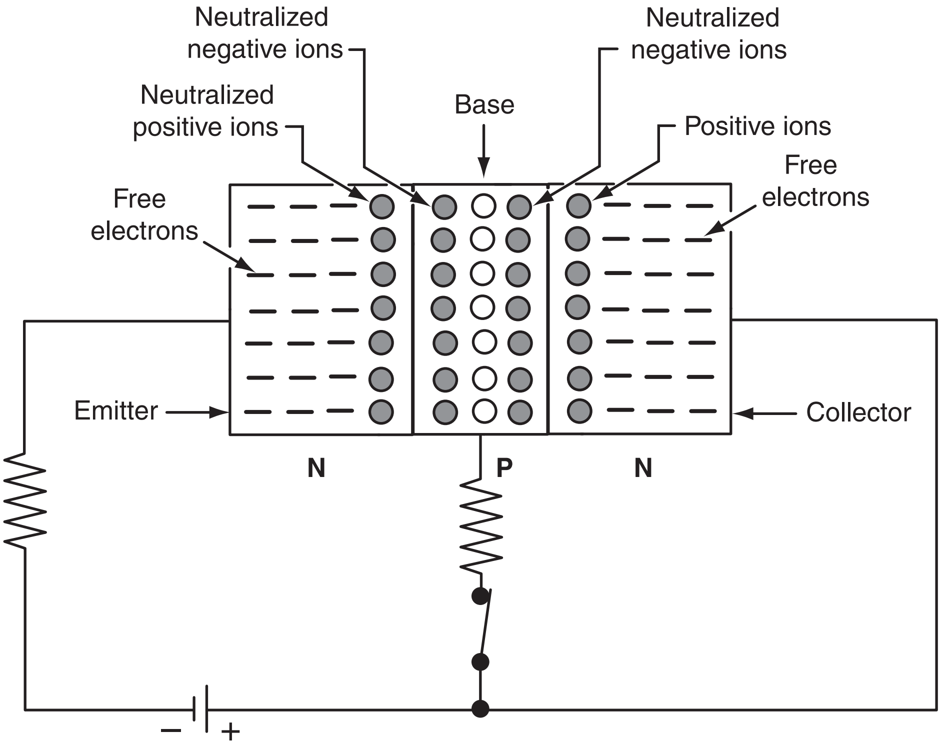

Neutralized negative ions
Neutralized positive ions
Base
Neutralized negative ions
Positive ions
Free electrons
Free electrons
Emitter
Collector
N
P
N
−
+

Figure 1–49 Forward biased NPN transistor.

If the biasing voltage is removed from the base, the barrier potential is restored at the junctions and both base and collector currents stop flowing. The base current flow caused by the forward biasing voltage between the base and the emitter allows current to flow between the collector and the emitter.

A transistor is also much like a relay in that a relatively small current through the base circuit controls a larger current through the collector. The amount of current through the base is determined by the amount of voltage and resistance in the base circuit. In fact, by carefully controlling the voltage applied to the base, the amount of current flow through the collector can also be controlled. If enough voltage is applied to the base to just start reducing barrier potential, a relatively small amount of current will begin to flow from the emitter to the collector. This is called *partial saturation.* As base voltage is increased, collector current increases. When enough voltage is applied to the base, full saturation is achieved. There is usually a small voltage spread between minimum and full saturation, and once full saturation is achieved, increasing voltage at the base will not increase collector current. If too much voltage is applied, the transistor will break down.

Transistors, therefore, act like switches that can be turned on by applying power to the base circuit. There are many types of transistors, but the most common fall into two categories: power and switching.

Power transistors are larger because the junction areas must be larger to pass more current across them. Passing current across the junctions produces heat; therefore, a power transistor must be mounted on something, ordinarily called a *heat sink*, which can draw heat from the transistor and dissipate it into the air. Otherwise, it will likely overheat and fail.

Switching transistors are much smaller. They are often used in information processing or control circuits, and they conduct currents ranging from a few milliamps (thousandths of an ampere) down to a few micro-amps (millionths of an ampere). They are most often designed for extremely fast on and off cycling rates, and the base circuits that control them are designed to turn them on at full saturation or to turn them off.

Effect of Temperature on a PN Junction

As the temperature of a semiconductor device goes up, the electrons in the valence ring move at a greater speed. This causes some to break out of the valence ring, creating more free electrons and holes. The increase in the number of free electrons and holes causes the depletion layer to become thinner, reducing the barrier potential. Barrier potential voltages of 0.7 for silicon and 0.3 for germanium semiconductors are true at room temperature only. At elevated temperatures, the lower barrier potential lowers the external bias voltage required to cause current to flow across the junction and raises the current flow.

This means that the expected operating temperature range of a semiconductor device must be considered when the circuit is being designed, and that when in operation, the operating temperature must be kept within that temperature limit. If the operating temperature goes higher, unless some kind of compensating resistance is used, current values will go up, and the semiconductor might be damaged.

Transistor Symbols and Transistor Operation

In electrical schematics, transistors are represented by symbols. Figure 1–50 shows the symbols that represent the components of a transistor: the collector, the base, and the emitter. When these components are arranged as in Figure 1–51, an NPN transistor is represented. (Most electrical schematics will put a circle around these three components, but exceptions will be seen in some schematics.) An NPN transistor can easily be identified because the emitter always points outward (simply pretend that the NPN acronym stands for *NEVER POINTING IN*). In Figure 1–51, the IC chip controls the signal to the base leg of the transistor in order to turn it on and off. This controlling signal must be of a positive polarity since the base is also positive (simply match the polarity of the applied voltage potential to the polarity of the base—or the middle letter of the transistor's acronym). But remember that the transistor's controlling circuit must also be completed through the emitter. Therefore, if the base takes a positive potential to forward bias the transistor, then the emitter must be connected to a negative potential. The negative potential applied to the emitter is always connected, thereby allowing the transistor to be controlled solely by the switching on and off of the positive potential applied to the base. Of course, if the emitter of an NPN transistor is always connected to a negative potential by reason of the controlling circuit, then it must also be connected to the same negative potential by reason of the controlled circuit. That is,

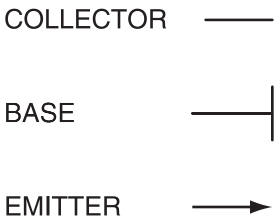


Figure 1–50 The components that make up a transistor.

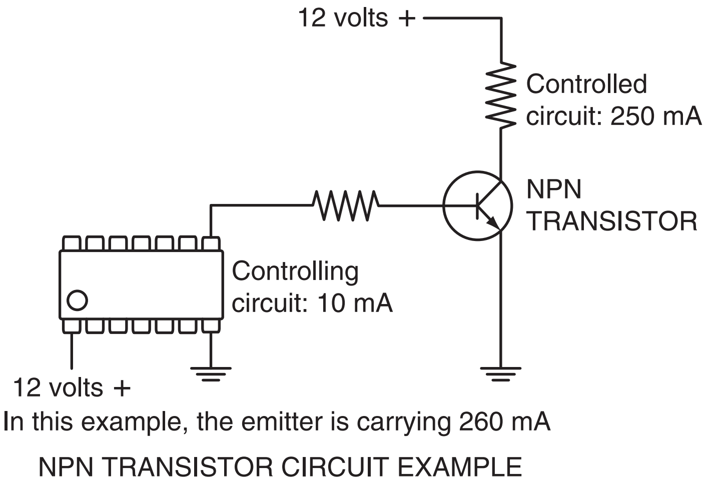

12 volts +
Controlled circuit: 250 mA
NPN TRANSISTOR
Controlling circuit: 10 mA
12 volts +
In this example, the emitter is carrying 260 mA
NPN TRANSISTOR CIRCUIT EXAMPLE

Figure 1–51 An NPN transistor circuit.

when the positive potential is switched on at the base, the collector will then gain electrical continuity with the emitter, thus applying the emitter's negative potential to whatever load is connected to the collector. Therefore, an NPN transistor is used for negative (or ground) side switching.

It should also be noted that the emitter carries both the base-to-emitter current flow of the controlling circuit as well as the collector-to-emitter current flow of the controlled circuit. Therefore, in Figure 1–51, if 10 milliamps is flowing through the base and emitter in order to forward bias the transistor and 250 milliamps is flowing from the collector through to the emitter once the transistor gains continuity, then the emitter is carrying a total of 260 milliamps.

Likewise, when these components are arranged as in Figure 1–52, a PNP transistor is represented. A PNP transistor can be identified by the fact that the emitter always points inward.

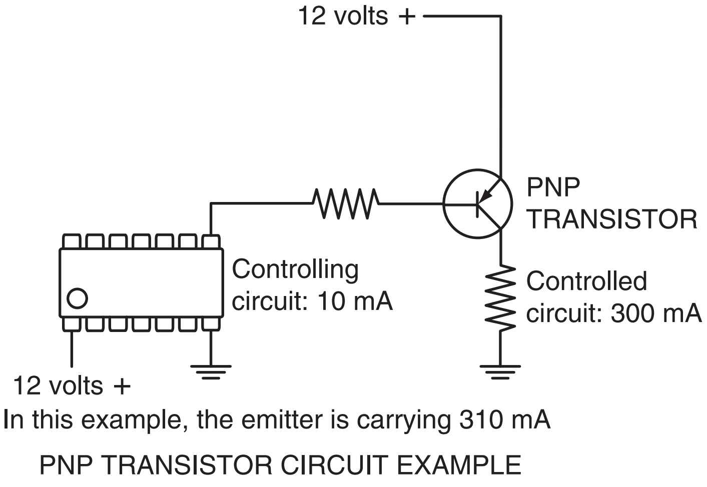

12 volts +
PNP TRANSISTOR
Controlling circuit: 10 mA
Controlled circuit: 300 mA
12 volts +
In this example, the emitter is carrying 310 mA
PNP TRANSISTOR CIRCUIT EXAMPLE

Figure 1–52 A PNP transistor circuit.

With a PNP transistor, a negative potential is applied to the base to forward bias the transistor and the emitter is always connected to a positive potential. Therefore, because the emitter has a positive potential applied by reason of the controlling circuit, it will also apply the same positive potential to and through the collector to the load when the transistor gains electrical continuity through it. Therefore, a PNP transistor is used for positive side switching of a load component. Although this is done less frequently than ground side switching, it is sometimes done for safety reasons, as explained in Chapter 3. Also, sometimes a computer must be able to reverse polarity in a circuit, as with a reversible DC motor, and will therefore use both NPN and PNP transistors to control the motor. An **H-gate** uses both types of transistors for this express purpose.

H-Gate Operation

An H-gate is defined as two pairs of transistors designed to be able to reverse the polarity applied to a load component, thereby reversing the direction of current flow through the load. In Figure 1–53, the load component is shown on the center leg of a circuit that looks like the letter “H.” If transistors “A” are turned on, current flows through the motor in one direction. If transistors “B” are turned on, the direction of current flow through the motor is reversed. The computer turns on the transistors in pairs only, either transistors “A” or transistors “B.” This is common in DC motors and stepper motors (discussed in Chapter 3) that are used to control the engine’s idle speed. H-gates are also used in controlling motorized shoulder safety belts and temperature/mode doors in heating, ventilation, and air conditioning systems. In an electrical schematic, an H-gate is more likely to be depicted as in Figure 1–54 or Figure 1–55.

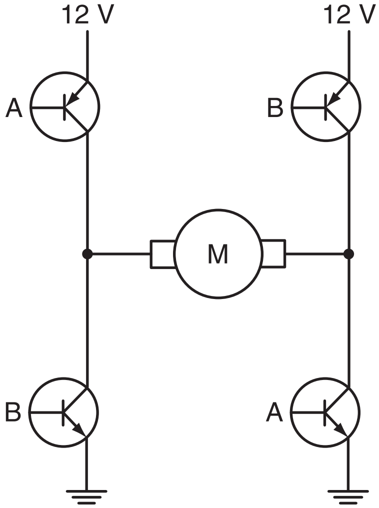


Figure 1–53 An H-gate.

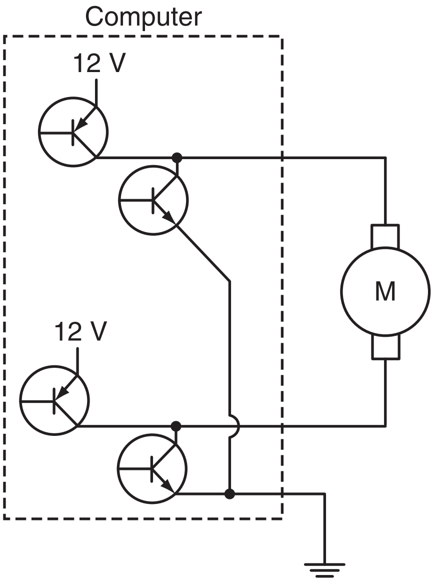


Figure 1–54 Electrical schematic depicting an H-gate.

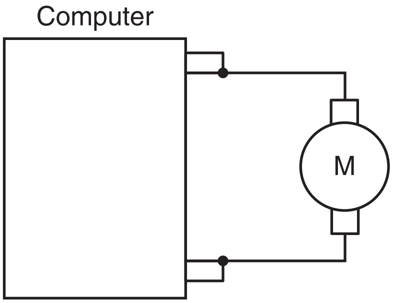


Figure 1–55 Electrical schematic depicting an H-gate.

INTEGRATED CIRCUITS

Thanks to scientific research, manufacturers of electronic systems produce microscopic transistors, diodes, and resistors. As a result, complete circuits are produced containing thousands of semiconductor devices and connecting conductor paths on a chip as small as two or three millimeters across. These IC chips (Figure 1–56), operating with current values as low as a few milliamps or less, can process information, make logic decisions, and issue commands to larger transistors. The larger transistors control circuits that operate on larger current values. Personal computers and the computers in today's vehicles became possible because of the development of ICs. Because the components in an IC are so small, they cannot tolerate high voltages. Care must be taken to avoid creating high-voltage spikes such as those produced by disconnecting the battery while the ignition is on. Care must also be taken when handling an electronic component containing ICs to avoid exposing it to an electrostatic discharge (ESD) such as those you sometimes experience when touching something with ground potential after walking across a carpet.

Many ICs are mounted in a chip with two rows of legs (one row of legs on each side of the chip), known as a **dual in-line package (DIP).** These legs provide terminals that are large enough to connect to a circuit board.

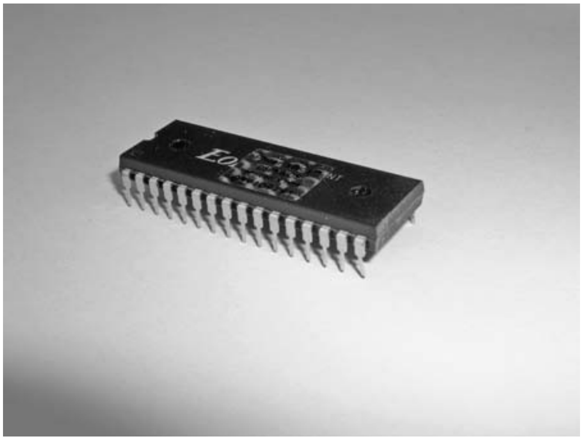


Figure 1–56 Integrated circuit (IC) chip.

Logic Gates

If two semiconductor elements placed back to back create the simplest semiconductor, the diode, and if three of these elements placed back to back form a transistor, when more than three of these elements are placed back to back, combinations of transistors known as logic gates are formed. Logic gates form the decision-making circuits within an IC chip; they are discussed in greater depth in Chapter 2.

Stepping Up the Amperage

In Figure 1–50, the logic gates within the IC chip can only carry a small amount of current, about 10 milliamps, which is enough to forward bias the transistor that controls a load that is external to the computer. (This transistor is known as a *driver.*) The transistor, in turn, carries the 250 milliamps (or ¼ amp) that the electromagnetic load draws (assuming the load's resistance is about 48 Ω in a 12-V circuit). If this load is the winding of a fuel pump relay, when the transistor turns on current flow through the relay's winding, the relay's electrical contacts will close and supply about 5 amps to the fuel pump motor. Thus, the IC chip is actually controlling a 5-amp load even though it is only capable of handling a few milliamps within itself. It is all about stepping up the amperage. The circuit in Figure 1–51 would operate similarly.

THE DIGITAL AGE

Voltage Characteristics

There are two ways of categorizing voltage: AC versus DC, as described in the early portion of this chapter, and analog versus digital.

AC versus DC Voltage. On an oscilloscope, a DC voltage will appear as a voltage that always stays above the ground level (zero volts), whereas an AC voltage goes both above and below ground.

Analog versus Digital Voltage. An analog voltage will appear on an oscilloscope as a voltage that is in a constant state of change, changing between a low value and a high value. While it will at times be at the extreme low or the extreme high value, at other times it will be at a level somewhere in between the two extremes. You could equate this to the dimmer switch that might be used to control the lighting in your dining room—it can be adjusted fully off, fully on and bright, or to a dimmed lighting level somewhere in between. An analog voltage may be either AC or DC.

A digital voltage, on the other hand, will be one of two voltage values (the two extremes) but will never be at a value in between. It is usually in either an "off" condition or an "on" condition, as with a standard light switch that allows the lights to be turned fully off or fully on and bright, but will not allow adjustment to some lighting level in between. It could also be one voltage value versus another voltage value. A digital voltage may also be either AC or DC.

Early computers made analog adjustments on the output side in response to analog inputs on the input side. By the late 1970s, analog computers were giving way to digital computers, and the latter began appearing on the automobile. The IC chips, transistorized circuits, and logic gates discussed earlier (and to be discussed further, throughout this textbook) are indicative of those computers that are known as digital computers.

The Four Digital Pulse Trains

You need to be familiar with the four rapidly switched voltage signals that are switched in a digital fashion. These are known as digital pulse trains. Each of these signals has two characteristics that can be measured: the signal's on-time and the frequency of the signal (the definition of frequency as it is used here is cycles per second, which is measured in hertz). Of these four digital signals, the last three retain a certain relationship that will enhance your understanding of them as you complete this portion. The four digital pulse trains are:

Binary Code or Serial Data. This digital pulse train is less closely related than the other three and will be discussed in depth in Chapter 2 and Chapter 9.

Variable Digital Frequency. Used by certain sensors on the input side of a computer, this allows for greater precision in reporting information to a computer. The frequency of this signal varies, but the on-time of the signal is stable. The frequency of this signal should be measured with a frequency counter known as a hertz meter. (Frequency is a count of how many full on *and* off cycles occur in the time frame of one second.) While you could measure the on-time of this signal, it is generally not beneficial to do so.

Variable Duty Cycle. This is used by a computer as a method of controlling some load components. The on-time of this signal varies, but the frequency of the signal is stable. The on-time of this signal should be measured with a duty cycle meter in order to measure the signal's on-time as a percentage of the total cycle. (In the absence of such a meter, a DC voltmeter or a dwell meter may be used, although the resulting measurement will have to be converted to percent of duty cycle on-time.) While you could measure the frequency of this signal, it is generally not beneficial to do so.

Variable Pulse Width. This is used by a computer as a method of controlling some load components. Both the on-time and the frequency of this signal will vary, but, like a variable duty cycle, it is of most importance to measure the on-time of the signal. However, the on-time is generally measured as a real time measurement (as milliseconds), unlike the method used to measure the on-time of a variable duty cycle.

The relationship of a variable frequency, a variable duty cycle, and a variable pulse width can be described as follows: If the frequency of a consistent digital pulse train was measured at 10 Hz (10 cycles per second), it could be derived from that measurement that a full on/off cycle would be

100 milliseconds long (one second or 1000 milliseconds divided by the frequency). If a duty cycle meter then showed that the duty cycle on-time was 6 percent, the pulse width of the signal would be 6 milliseconds (6 percent of 100 milliseconds).

SUMMARY

In this chapter we have looked at the basics of electricity and electrical relationships. We have also discussed the various types of electrical circuits and looked at the various methods that may be used to calculate their resistance. Then we took an in-depth look at the basic elements of all electronic systems, including diode construction and operation and transistor construction and operation. We also briefly discussed ICs and their use in today's vehicles. We then finished the chapter with a look at the relationship of variable frequency, variable duty cycle, and variable pulse width (three of the four digital pulse trains).

While much of this information, especially in the early part of this chapter, may seem quite basic considering the scope of this textbook, it is critically important that the reader be familiar and comfortable with *all* of the material discussed in this chapter before continuing further into this textbook. Because today's vehicles have so many electronic systems on-board, because today's vehicles no longer have any systems that are not controlled by a computer, and because this trend will continue to escalate in tomorrow's vehicles, it is critically important that the student have a solid foundation in his/her understanding of the electrical concepts discussed in this chapter before continuing to study the use of on-board computers in controlling engine performance or any other electronic system.

▲ DIAGNOSTIC EXERCISE

A technician has used his ohmmeter to measure the resistance of a light bulb's filament and finds that it measures 6 Ω. He then proceeds to power the light bulb using a 12-V battery as the source. With the bulb now illuminated, he uses his ammeter to measure the current draw and is surprised to find that it is remarkably lower than he had calculated using the Ohm's law formula. Why would this be so?

Review Questions

1. Two technicians are discussing electrical and electronic systems as used on the automobile. Technician A says that an electrical system may or may not be under the electronic control of a computer depending upon the system and how old the vehicle is. Technician B says that modern vehicles use electronic control systems to control virtually every system in the vehicle. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. Which of the following has a negative charge?
   A. Neutron
   B. Electron
   C. Proton
   D. All of the above
3. Which of the following best describes the electron layer of an atom that is referred to as the atom's valence ring?
   A. The inner shell
   B. The second shell
   C. The third shell
   D. The outer shell
4. Which of the following best describes the *electrical pressure* that pushes electrons through a circuit?
   A. Resistance
   B. Amperage
   C. Voltage
   D. Capacitance
5. Which of the following best describes the *current flow of electrons* through a circuit?
   A. Resistance
   B. Amperage

   C. Voltage
   D. Capacitance
6. Technician A says that voltage drop always occurs in a circuit, regardless of whether or not current is flowing. Technician B says that if the circuit is complete and current is flowing, most of the voltage drop should occur across the load. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
7. Which of the following would increase the resistance of a wire?
   A. A wire of a shorter length
   B. An increase in the temperature of the wire
   C. A larger diameter (lower gauge number) of wire
   D. All of the above
8. Which of the following, while utilized in most circuits, is not essential to have an operating circuit?
   A. Voltage source
   B. Switch
   C. Load component
   D. Circuitry or current conductors
9. A series circuit is connected to a 12-V battery and is flowing ½ amp of current. How much resistance is present in the circuit?
   A. 6 Ω
   B. 12 Ω
   C. 18 Ω
   D. 24 Ω
10. A parallel circuit has two branches. One branch has a load with 10 Ω of resistance. The other branch has a load with 30 Ω of resistance. What is the total resistance of the parallel circuit?
   A. 7.5 Ω
   B. 15 Ω
   C. 20 Ω
   D. 40 Ω
11. A parallel circuit has three branches. One branch has a load with 18 Ω of resistance. Another branch has a load with 22.5 Ω of resistance. The third branch has a load with 30 Ω of resistance. What is the total resistance of the parallel circuit?
   A. 7.5 Ω
   B. 18 Ω
   C. 22.5 Ω
   D. 70.5 Ω
12. A series circuit has two loads. The first load has 10 Ω of resistance and the second load has 30 Ω of resistance. What is the total resistance of this circuit?
   A. 7.5 Ω
   B. 15 Ω
   C. 20 Ω
   D. 40 Ω
13. Which of the following could affect the ability of an electrical circuit to operate properly?
   A. Open wire or connector
   B. Short to power or ground
   C. Unintended high resistance within the circuit
   D. All of the above
14. If a circuit's current flow is too high, which of the following could be at fault?
   A. An open exists in the circuit.
   B. A short exists in the circuit.
   C. Unintended high resistance exists in the circuit.
   D. The circuit has a loose connection, causing an intermittent open.
15. A diode may be used for all except which of the following?
   A. Switching current flow on and off
   B. AC-to-DC rectification
   C. Voltage spike suppression
   D. Controlling current flow paths in circuits that share a common load
16. What type of component is used by a computer to perform ground side switching of a load component?
   A. Diode
   B. NPN transistor
   C. PNP transistor
   D. Capacitor
17. What is contained in an H-gate to allow it to reverse current flow within a load device?
   A. Two pairs of resistors
   B. Two pairs of diodes

C. Two pairs of transistors
D. One pair of transistors

18. Technician A says that the terms *AC voltage* and *analog voltage* have the same meaning and are therefore interchangeable. Technician B says that the terms *DC voltage* and *digital voltage* have the same meaning and are therefore interchangeable. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

19. Which of the digital pulse trains varies both the on-time and the frequency of the signal?
A. Binary code (serial data)
B. Variable digital frequency
C. Variable duty cycle
D. Variable pulse width

20. Why should you, as a student, be familiar and comfortable with *all* of the material discussed in this chapter?
A. Because today's vehicles have many electronic systems on board.
B. Because virtually all systems on modern vehicles are controlled electronically.
C. Because the trend of adding electronic systems on vehicles will continue to escalate in the future.
D. All of the above

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Chapter 2

Computers in Cars

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Recognize why all modern vehicles are equipped with a computerized engine control system as well as many other computerized control systems.
- ☐ Describe the major components of a computer.
- ☐ Be able to list the major exhaust emissions.
- ☐ Describe what is meant by a stoichiometric air/fuel ratio.
- ☐ Understand why a PCM will attempt to maintain a stoichiometric air/fuel ratio when in closed loop.
- ☐ Describe the difference between open loop and closed loop operation.

KEY TERMS

Analog
Baud Rate
Bit
Byte
Clock Oscillator
Closed Loop
Digital
Driveability
Engine Calibration
Feedback
Interface
KAM
Logic Gates
Memory
Microprocessor
Open Loop
Powertrain Control Module (PCM)
PROM
RAM
Reference Voltage Regulator
ROM
Signal or Voltage Signal
Stoichiometric

WHY COMPUTERS?

In 1963, positive crankcase ventilation systems were universally installed on domestic cars as original equipment. People in the service industry felt that dumping all of those crankcase gasses into the induction system would plug up the carburetor and be harmful to the engine. Instead, engine life doubled.

In 1968, exhaust emission devices were universally applied to domestic cars. Compression ratios began to go down; spark control devices denied vacuum advance during certain driving conditions; thermostat temperatures went up; air pumps were installed; heated air intake systems were used during warm-up; and air/fuel ratios began to become leaner. Through the 1970s, evaporation control systems, exhaust gas recirculation (EGR) systems, and catalytic converters were added. Although some of the emissions systems actually tended to improve **driveability** and even improve fuel mileage, for the most part, in the early days of emission controls, driveability and fuel mileage suffered in order to achieve a dramatic reduction in emissions.

In 1973 and 1974, when domestic car fuel economy was at its worst, we also experienced an oil embargo and an energy shortage. The federal government responded by establishing fuel mileage standards in addition to the already established emissions standards. By the late 1970s, car manufacturers were hard-pressed to meet the ever more stringent emissions and mileage standards, and the standards set for the 1980s looked impossible (Figures 2–1 and 2–2). To make matters worse, not only did the consumer's car get poor fuel mileage, it had poor driveability (idled rough, often hesitated or stumbled during acceleration if the engine was not fully warmed up, and had little power). What made the situation so difficult was that the three demands—lower emissions, better mileage, and better driveability —were largely in opposition to each other using the technology available at that time (Figure 2–3).

What was needed was a much more precise way to control engine functions, or **engine calibration.** The automotive industry had already looked to **microprocessors**—processors contained on integrated circuits. In 1968, Volkswagen introduced the first large-scale production, computer-controlled electronic fuel injection (EFI) system, an early version of the Bosch D-Jetronic system. In 1975, Cadillac introduced a computer-controlled EFI system. In 1976, Chrysler introduced a computer-controlled electronic spark control system, the Lean-Burn system. And in 1977, Oldsmobile introduced a computer-controlled electronic spark control system known as MISAR (micro-processed-sensing automatic regulation). All of these systems had three things in common: They all controlled only one engine function, they all used an **analog** computer (a mechanism that continuously varies within a given range with time needed for the change to occur), and none of them started any landslide movement toward computer controls.

By the late seventies, the electronics industry had made great strides with **digital** microprocessors. These small computers, with their comparatively low cost, compact size and weight, great speed, and application flexibility, proved to be ideal for the industry. Probably the most amazing feature of the digital computer is its speed. To put it into perspective, one of these computers controlling functions on an eight-cylinder engine running at 3000 RPM can send the spark timing command to fire a cylinder; reevaluate input information about engine speed, coolant temperature, engine load, barometric pressure, throttle position, air/fuel mixture, spark knock, and vehicle speed; recalculate air/fuel mixture, spark timing, and whether to turn on the EGR valve, canister purge valve, and the torque converter clutch; and then take a short nap before sending the commands, all before the next cylinder fires. The computer is so much faster than even the fastest engine that it spends most of its time doing nothing but counting time on its internal clock.

At last the automotive manufacturers had the technology to precisely monitor and control, to instantly and automatically adjust, while driving, enough of the engine's calibrations to make their vehicles comply with the government's demands for emissions and fuel economy, while still satisfying the consumer's demands for better driveability. This brought about what is probably the first real revolution in the automotive industry's recent history; other changes have been evolutionary by comparison.

After some experimental applications in 1978 and 1979 and some limited production in 1980, the whole domestic industry was using comprehensive computerized engine controls in 1981. At the same time, General Motors alone produced more computers than anyone else in the world and used half of the world's supply of computer parts.

Ultimately, there are five reasons why computers are being used to control so many systems on the automobile, including both engine management systems and non-engine systems. When compared to mechanical methods of controls, computers provide:

- more precise control,
- faster response,

EMISSION REQUIREMENTS FOR PASSENGER CARS (PC)

Measured in Grams-per-Mile (GPM)

	Hydrocarbons (HC)		Carbon Monoxide (CO)		Oxides of Nitrogen (NO_X)	
	Federal	California	Federal	California	Federal	California
1978	1.50	0.41	15.0	9.0	2.0	1.5
1979	0.41	0.41	15.0	9.0	2.0	1.5
1980	0.41	0.39	7.0	7.0	2.0	1.0
1981	0.41	0.39	3.4	7.0	1.0	0.7
1982–1995 Tier 0	0.41	0.39	3.4	7.0	1.0	0.4
1993–2003 Tier 1	0.41	0.25	3.4	3.4	0.4 (1)	0.4

Tier 0 passenger cars phased out as follows:

	1992	1993	1994	1995	1996	1997
Federal	100%	100%	60% max	20% max	0%	
California	100%	60% max	20% max	0%		

Tier 1 passenger cars phased in as follows:

	1993	1994	1995	1996	1997-2003
Federal		40% min	80% min	100%	100%
California	40% min	80% min	100%	100%	100%

1994 and newer vehicles also include the following vehicles (as defined by their maximum emissions):

	HC	CO	NO_X
TLEV (Transitional Low-Emission Vehicle)	0.41	3.4	0.4
LEV (Low-Emission Vehicle)	0.41	3.4	0.2
ULEV (Ultra-Low-Emission Vehicle)	0.41	1.7	0.2
ZEV (Zero-Emission Vehicle)	0.00	0.0	0.0

Tier 2 vehicles are being phased in (beginning in 2004) and will for the first time put all Light Duty Vehicles (LDVs) under the same standard, including passenger cars, SUVs, minivans, and light pickup trucks. Tier 2 requires reduced sulfur in gasoline and also reduces the NO_X standard as follows:

	2004	2005	2006	2007	2008	2009
Max NO_X in GPM	0.60	0.20 (phased-in reduction)			0.07 50% of all LDVs	0.07 100% of all LDVs

(1) Diesel-fueled vehicles allowed 1.0 GPM through the 2003 model year

Figure 2–1 Federal and California emissions standards.

CORPORATE AVERAGE FUEL ECONOMY STANDARDS (1)

Model Year	Passenger Cars	Light Trucks (2),(3)		
		Two-Wheel Drive	Four-Wheel Drive	Two- & Four-Wheel Drives Combined (4)
1978	18.0 MPG			
1979	19.0 MPG	17.2 MPG	15.8 MPG	
1980	20.0 MPG	16.0 MPG	14.0 MPG	
1981	22.0 MPG	16.7 MPG	15.0 MPG	
1982	24.0 MPG	18.0 MPG	16.0 MPG	17.5 MPG
1983	26.0 MPG	19.5 MPG	17.5 MPG	19.0 MPG
1984	27.0 MPG	20.3 MPG	18.5 MPG	20.0 MPG
1985	27.5 MPG	19.7 MPG	18.9 MPG	19.5 MPG
1986	26.0 MPG	20.5 MPG	19.5 MPG	20.0 MPG
1987	26.0 MPG	21.0 MPG	19.5 MPG	20.5 MPG
1988	26.0 MPG	21.0 MPG	19.5 MPG	20.5 MPG
1989	26.5 MPG	21.5 MPG	19.0 MPG	20.5 MPG
1990	27.5 MPG	20.5 MPG	19.0 MPG	20.0 MPG
1991	27.5 MPG	20.7 MPG	19.1 MPG	20.2 MPG
1992	27.5 MPG			20.2 MPG
1993	27.5 MPG			20.4 MPG
1994	27.5 MPG			20.5 MPG
1995	27.5 MPG			20.6 MPG
1996–2004	27.5 MPG			20.7 MPG
2005	27.5 MPG			21.0 MPG
2006	27.5 MPG			21.6 MPG
2007	27.5 MPG			22.2 MPG

(1) CAFE standards were occasionally revised downward by the Federal government, as with the passenger car standard in 1986 as compared to 1985.

(2) Light trucks are defined as those trucks having a Gross Vehicle Weight Rating (GVWR) of 6000 lbs or less for model year 1979 (and older) and 8500 lbs or less for model year 1980 and newer vehicles.

(3) For model years 1982–1991, manufacturers could comply with the two-wheel and four-wheel drive standards or could choose to combine all of their light trucks and comply with the combined standard.

(4) Beginning in the 2008 MY, the CAFE standard for light trucks will be based on vehicle size, instead of one average standard for all light trucks.

Figure 2–2 Federally imposed fuel economy standards.

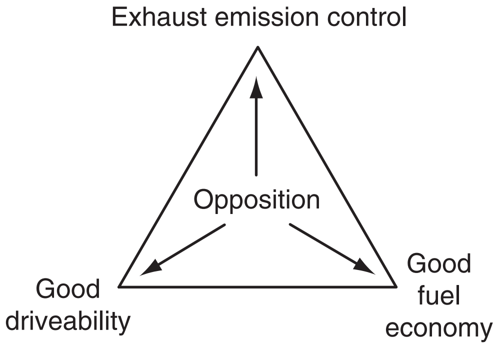


Figure 2–3 Opposition of exhaust emissions, driveability, and fuel economy.

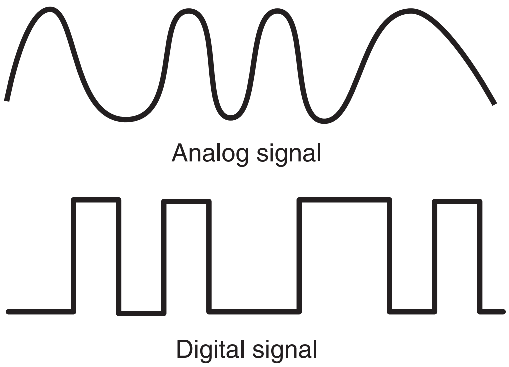


Figure 2–4 Analog signals can be constantly variable. Digital signals are either on/off or low/high.

- increased dependability,
- the potential to add additional features and functions, and
- enhanced diagnostic capabilities.

HOW COMPUTERS WORK

Contrary to some "informed" opinions and numerous suggestions from popular movies, computers cannot think for themselves. When properly programmed, however, they can carry out explicit instructions with blinding speed and almost flawless consistency.

Communication Signals

A computer uses voltage values or voltage pulses as communication signals; thus, voltage is often referred to as a **signal** or a **voltage signal.** There are two types of voltage signals: analog and digital (Figure 2–4). An analog signal's voltage is continuously variable within a given range, and time is needed for the voltage to change. An analog signal is generally used to convey information about a condition that changes gradually and continuously within an established range. Temperature-sensing devices usually return analog signals. Digital signals also vary but not continuously, and time is not needed for the change to occur. Turning a switch on and off creates a digital signal; voltage is either there or it is not. Digital signals are often referred to as *square wave signals.*

Binary Code. A computer's internal components communicate with each other using a series of digital signals that equate to a binary numbering system made up of ones and zeros; voltage above a given threshold value converts to 1, and voltage below that converts to 0. Each 1 or 0 represents a **bit** (or binary digit) of information. Eight bits equal a **byte** (or binary term, sometimes referred to as a *word*) to an eight-bit computer. All communication between the microprocessor, the memories, and the input and output interfaces is in binary code, with each exchange of information being in the form of a byte of binary code. (Computers also communicate externally with other computers using the same concept—see Chapter 9.) This form of communication using binary code is also referred to as serial data.

In order to understand the binary (base two) numbering system, it is first important to understand the decimal (base ten) system that you are already accustomed to using. Base ten has ten single digits (zero through nine). A single digit representing the value of ten does not exist, but rather another column must be added. In a base ten numbering system, each column's value (as it moves from right to left) is ten times the previous column's value. In all bases, the right hand column is ones. Therefore, the number 8763 is actually eight groups of thousands (8 × 1000), seven groups of hundreds (7 × 100), six groups of tens (6 × 10), and three ones (3 × 1), thus adding up to what we know to be eight thousand, seven hundred, sixty-three.

Any base that you have reason to create can be created using these same principles. For example, if you had reason to create a base seven numbering system, you would have seven single digits (zero through six), you would not have a single digit representing the value of seven but would, rather, have to create another column, and beginning with the right hand column that represents ones, each column's value would be seven times the previous column's value (ones, sevens, forty-nines, and so on). However, these column values are still base ten values and, therefore, give you a way to convert the base seven number to a decimal (base ten) number.

With a base two (binary) numbering system, you have only two single digits, zero and one. There is no single digit representing the value of two so another column must be created. And in a base two numbering system, each column's value will be two times the previous column's value. So, since the first column is always ones, the column values are (right-to-left) ones, twos, fours, eights, sixteens, and so on. These column values are base ten values, though, so you can convert a base two number to decimal (base ten) by multiplying the one or the zero by the column value above it and then adding up the sum of it all. In Figure 2–5A, $0 \times 128 = 0$; $1 \times 64 = 64$; $1 \times 32 = 32$; $1 \times 16 = 16$; $1 \times 8 = 8$; $0 \times 4 = 0$; $1 \times 2 = 2$; and $0 \times 1 = 0$. Then add it up: $0 + 64 + 32 + 16 + 8 + 0 + 2 + 0 = 122$. In reality, you simply add up the column value of any column with a 1 in it and ignore the columns that have a zero.

In Figure 2–5B, a 1 is shown in every column, adding up to the maximum value that can be had when a binary number is only carried out to eight places: 255. This means that if you began with seven zeros and a one (representing a decimal value of 1) and increased the value by one at a time, you would have 255 different combinations of zeros and ones. But this totally ignores the decimal value of zero (eight zeros in binary). With zero also added in, there are actually 256 different combinations of zeros and ones when carried to eight places. Restated, an eight-bit computer has 256 different words in its language. All you really need to do to find how many different combinations of zeros and ones are available to a computer (how many words are in its language) is to take the last column's value that the binary is carried out to and double it.

What this really means is that an eight-bit computer can divide an input voltage into 256 different binary communications for its internal decision making. For example, a throttle position sensor that operates in a range of zero to five volts would have a new binary number assigned to its voltage with every 0.02 V change in the analog input signal. Or an eight-bit computer may be able to assign 256 different steps to an idle air control stepper motor (from step 0 through step 255).

When carried to 16 places (a 16-bit computer), the last column's value is 32,768, thus allowing for 65,536 different words in a 16-bit computer's vocabulary. When carried to 24 places (a 24-bit computer), the last column's value is 8,388,608, thus allowing for 16,777,216 different words in a 24-bit computer's vocabulary. And when carried to 32 places (a 32-bit computer), the last column's value is 4,294,967,295, thus allowing for 8,589,934,590 different words in a 32-bit computer's vocabulary. And a 64-bit computer . . . well, you get the idea.

Automotive computers used 8-bit microprocessors for many years, but as these computers have taken on more responsibility and have had to communicate more rapidly, 16-bit and 32-bit

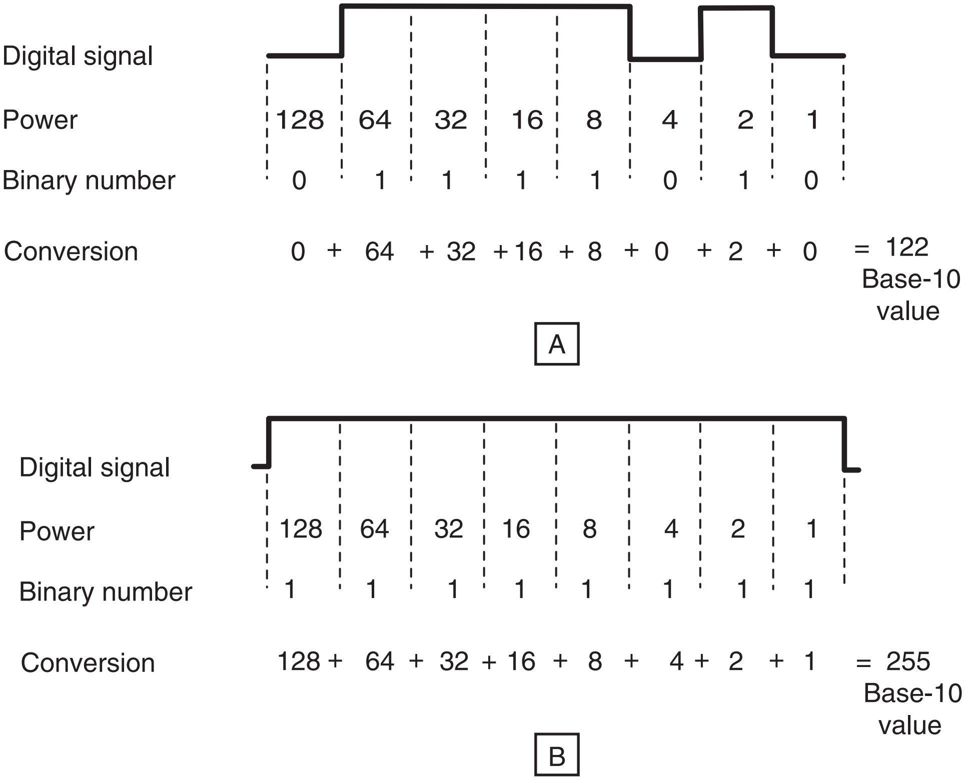


Figure 2–5 Binary numbers.

computers have become commonplace in the automobile. And 64-bit computers are now commonplace in home computers.

Baud Rate. The frequency of the bits of binary code as they are communicated is known as the computer's **baud rate.** Baud rate is expressed in bits per second (b/S), kilobits per second (Kb/S), or megabits per second (Mb/S). For example, a computer with a baud rate of 10,400 b/S (or 10.4 Kb/S) is able to communicate 10,400 bits of binary code information per second.

Baud rates in automotive computers have gone up considerably since those used in the early 1980s. The computers used by General Motors in the early 1980s had a baud rate of 160 b/S (some of these computers were still found on applications even in the late 1980s), while their P-4 electronic control module introduced in the late eighties has a baud rate of 8192. Ford introduced a computer in 1988 with a baud rate of 12,500 b/S. Modern computers have baud rates that are even faster, with General Motors and Chrysler using 10,400 b/S and Ford using 41,600 b/S as of the mid- to late 1990s. And computers with even faster baud rates are found in the automobile today, with the fastest baud rates between 1 Mb/S and 10 Mb/S.

Internal Circuits of the Computer

Microprocessor or Central Processing Unit (CPU). The microprocessor (an IC chip), also referred to as the central processing unit (CPU), is the heart of a computer and has the task of making all decisions to be made by the computer. The CPU records input information. It then compares this information with the internal programs. This results in a specific response on the output side of the computer. It then sends the proper commands so as to control the output circuits appropriately. In essence, the CPU performs the data processing of the computer.

Interface. The microprocessor makes all of the decisions, but it relies on several support functions, one of which is the **interface.** A computer has an input interface and an output interface (Figure 2–6). The interface has two functions: it protects the delicate electronics of the microprocessor from the higher voltages of the circuits attached to the computer, and it translates input and output signals. The input interface translates all sensor input data (including DC analog signals, AC analog signals, and variable digital frequency signals) to digital binary code. It is sometimes referred to as the analog-to-digital or A/D converter. The output interface, or D/A converter, translates digital binary signals to analog to control the actuators and other output signals. The transistors that control the outputs are located in the output interface and are called *drivers*.

Memories. The microprocessor of a computer performs the calculations and makes all of the decisions, but it cannot store information. The computer is therefore equipped with information storage capability called **memory.**

There are two ways that computer memories are classified: An IC memory chip may be in the form of either read only memory **(ROM)** or random access memory **(RAM),** and this memory chip may be classified as either volatile or nonvolatile.

If the memory is classified as any form of ROM, the CPU cannot change or write new information into it, but, rather, can only read from it. But if the memory is classified as RAM, the CPU can write new information into it and can read it back. If the memory is classified as being volatile, the memory will be erased when power is removed from the computer (although many volatile memories are kept alive for some period of time following a battery disconnect by capacitors within

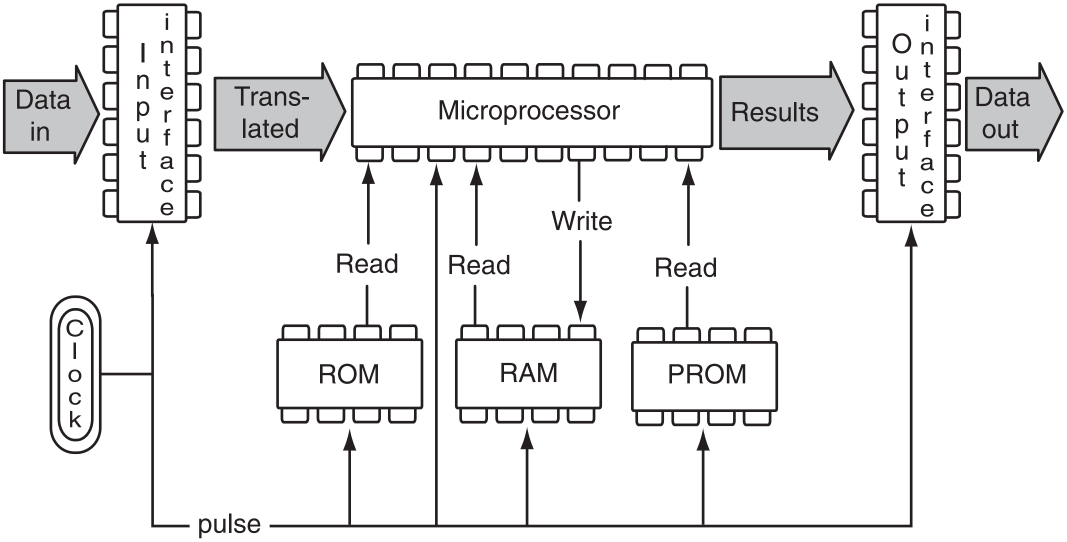


Figure 2–6 Interaction of the microprocessor and its support system.

the computer designed for this purpose). And if the memory is classified as being nonvolatile, it is retained indefinitely when power is removed.

In basic computer theory, the automotive computer has three types of memory: a ROM, a programmable read-only memory **(PROM),** which is simply another form of ROM, and a RAM (Figure 2–7). (Some manufacturers change these concepts slightly by adding additional memories and combining others.)

ROM. The ROM IC chip contains permanently stored information that instructs (programs) the microprocessor on what to do in a very basic sense and in response to input data. For example, the ROM instructs the CPU as to the order in which it should look at the sensor values and how to react to these values when controlling actuators on the output side of the computer. In an engine computer, the ROM is nonvolatile. The ROM IC chip is soldered into the computer and is not easily removed.

PROM. The PROM IC chip differs from the ROM in that it is programmed with regard to a specific vehicle. Information stored in the PROM is stored in the form of electronic lookup tables or charts (similar in concept to the tables or charts that one might find in the back of a chemistry or math textbook, except that they are recorded electronically). These tables are also sometimes referred to as *maps.* These charts enable the computer to respond to a specific combination of input conditions when making a decision concerning an actuator. For example, Figure 2–8 shows an ignition timing map that shows how much spark advance the computer has been programmed to add in response to various combinations of engine speed and load. Figure 2–9 shows a pulse width control map that shows how much fuel injector on-time the computer should give the fuel injectors according to various combinations of engine speed and load. And both of these control systems also add in other pieces of input information not shown in these charts, including throttle position, engine temperature, intake air temperature, and so on. These electronic charts allow the CPU to precisely control a system on the output side according to various combinations of many inputs.

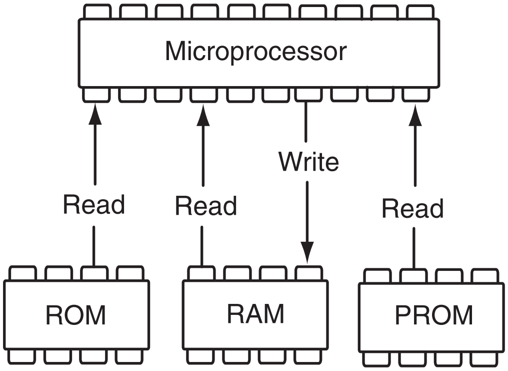


Figure 2–7 The three types of memory within a computer.

In an engine computer, the PROM is nonvolatile. The PROM IC chip may be reprogrammed on modern vehicles (known as re-flashing) in order to update the computer's strategies as needed. Some early models allowed the technician to replace the PROM IC chip with one containing a revised program—these early systems included General Motors vehicles throughout the 1980s and Ford EEC I, II, and III systems from 1978 through as late as 1984 (known by Ford as the *engine calibration assembly*).

RAM. The RAM IC chip is where information is stored temporarily by the CPU. For example, as each sensor's value is received by the CPU, the CPU records it in RAM. The CPU will update these values as new information is received. The CPU also records strategy results in RAM, including adaptive strategy values such as fuel trim (discussed in Chapter 4). Diagnostic trouble codes are also recorded in RAM when the computer determines that a fault exists.

In an engine computer, the RAM is volatile. (There are two kinds of RAM: volatile and nonvolatile. A volatile RAM, sometimes called keep-alive memory **[KAM],** must have a constant source of voltage to continue to exist and is erased when

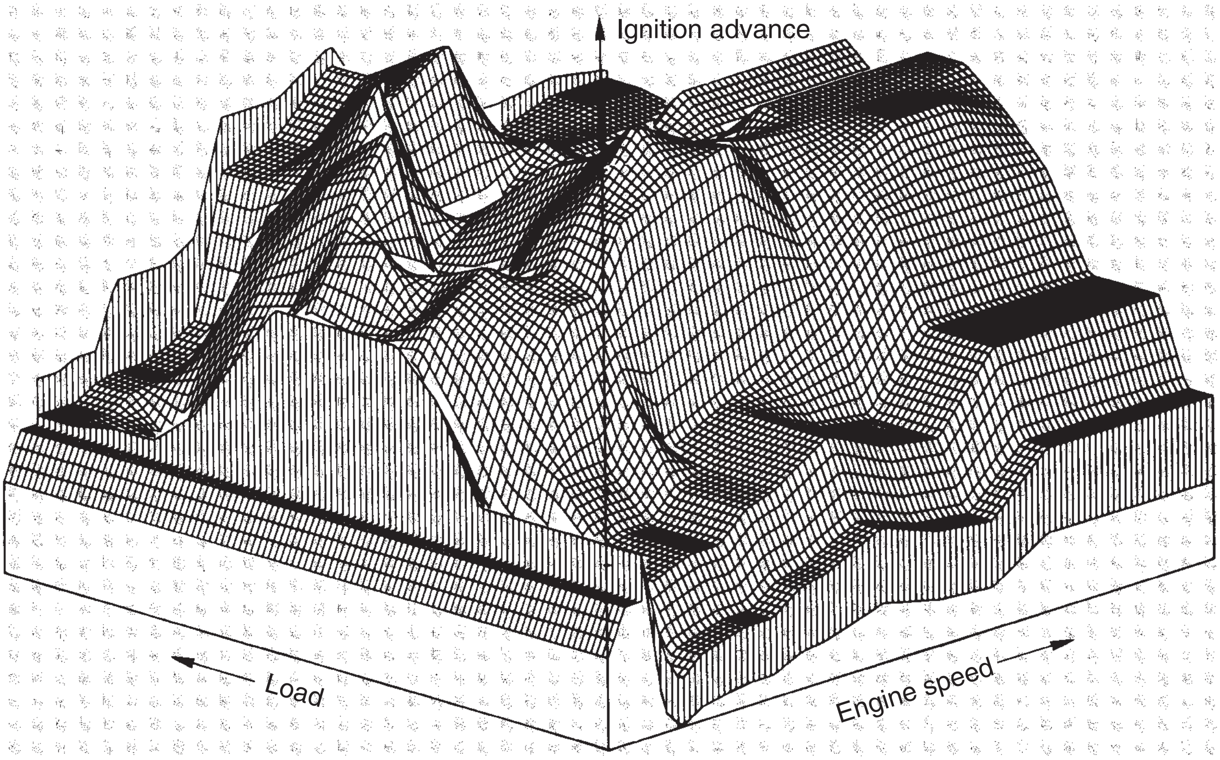


Figure 2–8 Ignition timing map. (Reprinted with permission from Robert Bosch Corporation.)

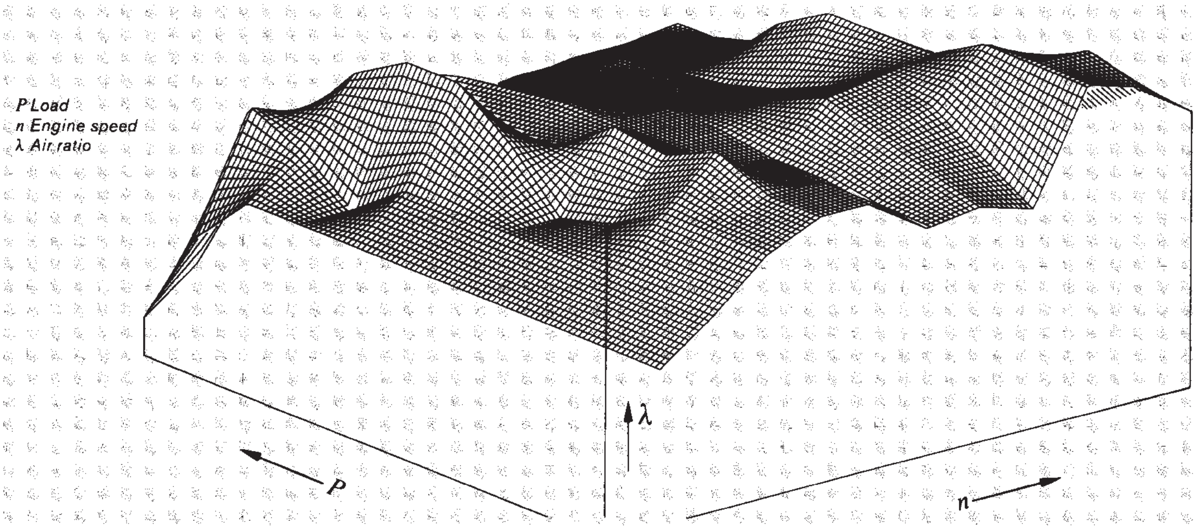


Figure 2–9 Pulse width control map. (Reprinted with permission from Robert Bosch Corporation.)

disconnected from its power source. In automotive applications, a volatile RAM is usually connected directly to the battery by way of a fuse or fusible link so that when the ignition is turned off, the RAM is still powered. A nonvolatile RAM does not lose its stored information if its power source is disconnected. Vehicles with digital odometers store the vehicle's accumulated mileage in a nonvolatile RAM.) The RAM is also soldered in place and not easily removed.

The terms *ROM, PROM,* and *RAM* are fairly standard throughout the computer industry; however, vehicle manufacturers do not all use the same terms in reference to computer memory. For example, as mentioned earlier, instead of using the term *PROM,* Ford calls its equivalent unit an *engine calibration assembly*. Another variation of a *PROM* is an *E-PROM.* An E-PROM has a housing with a transparent top that will let light through. If ultraviolet light strikes the E-PROM, it reverts back to its unprogrammed state. To prevent deprogramming or memory loss, a cover must protect it from light. The cover is often a piece of tape. An E-PROM is sometimes used where ease of changing stored information is important. General Motors uses one as a PROM on some applications because it has more memory capacity.

Another variation of RAM: Ford divided the RAM into two volatile memories with their EEC-IV system. One portion, still called RAM, is powered through the ignition switch. The other portion, called KAM, is powered by a fuse straight from the battery. Therefore, when the ignition is turned off, the KAM remains powered and its stored information is retained, but the RAM loses its memory. Information stored in this RAM is not critical to retain when the ignition is turned off, including information such as the last value obtained from the throttle position sensor—as soon as the ignition is switched on again, the CPU will re-gather this information. Other types of memory unique to specific manufacturers are introduced in appropriate chapters.

Clock Oscillator. To maintain an orderly flow of information into, out of, and within the computer, a quartz crystal, called a **clock oscillator,** is used to produce a stream of continuous, consistent voltage pulses (Figure 2–6). The clock oscillator is a small silver, oval can, as shown in Figure 2–10, between the IC chip and the transistor. The frequency of these clock pulses determines the computer's clock speed. Once the clock speed is established, the computer's baud rate can be established, thereby establishing an orderly flow of information within, or from, the computer.

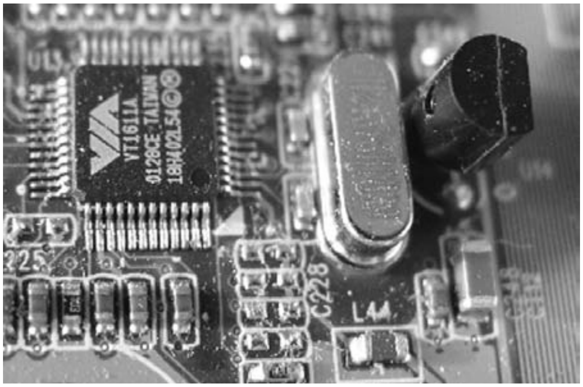


Figure 2–10 Clock oscillator on control module board.

Reference Voltage Regulator. The **reference voltage regulator** looks like a transistor, is approximately ¼ inch square, and has three legs (electrical terminals) attached to it. The three terminals are voltage in, ground, and voltage out. The ground terminal is common to both the input and output legs. If a voltage above 9.6 V is provided to the input terminal, then the regulator, using a rapid pulse width modulation, outputs a steady 5 V. (On some late seventies and early eighties vehicles, this output was 9 V. But this value became standardized worldwide at 5 V by 1984.) This 5-V reference signal, sometimes referred to as *VREF,* is provided to the internal circuits of the computer, including the **logic gates** contained within the CPU (discussed later in this chapter) and for communication between the CPU, the interfaces, and the memories. The computer also provides this 5-V signal to external sensor circuits—those sensors that require a

5-V signal in order to operate. (One exception: On modern Chrysler vehicles, the computer supplies an 8-V signal to the vehicle speed sensor, the crankshaft position sensor, and the camshaft position sensor.)

External Circuits of the Computer

Inputs. Inputs are defined as circuits that operate as informants. That is, they *inform* the computer of the various conditions that exist within the vehicle. As a result, these circuits are generally high-resistance circuits that operate at ultra-low current flows. Their primary purpose is to communicate values to the computer through voltage signals. Input circuits include:

- Sensor circuits: A sensor either generates a voltage or changes resistance in some manner so as to modify a voltage that is then sent to the computer. Common sensors include the oxygen sensor in the exhaust stream, the throttle position sensor, the engine coolant temperature sensor, and numerous other sensors. Sensor circuits also include those circuits that monitor the operation of a simple switch, such as those switches inside an automatic transmission that, in combination, can inform the engine computer of the gear that the transmission is operating in. Other switches may monitor power steering pressure, whether the brake pedal is depressed, or whether air conditioning has been selected.
- Diagnostic monitor circuit: Beginning in the mid- to late 1980s, manufacturers began monitoring output circuits with input circuits known as **feedback** circuits. For example, both GM and Ford ran a fuel pump monitor circuit off the circuit between the fuel pump relay and the fuel pump motor so that when the computer's driver (transistor) energized the fuel pump relay, the feedback circuit would inform the computer as to whether the relay had actually been energized successfully. Similarly, Ford ran a feedback circuit off the negative terminal of the ignition coil known as the ignition diagnostic monitor (IDM) so that the computer could monitor whether the ignition module successfully fired the ignition coil. The use of such feedback circuits enhances the computer's ability to aid the technician in diagnosis of these systems.
- Informational input circuits from other computers: Computers share information with each other. While these input circuits do not come directly from a sensor, they are used to communicate sensor values or other important information, thus operating as an output circuit of the computer sending the information and as an input circuit of the computer receiving the information. On older vehicles, these circuits were usually dedicated to one message, such as a cooling fan control module informing the engine computer that the cooling fan relay had been energized so that the idle speed could be adjusted to compensate for the additional load. On newer vehicles, these circuits are commonly known as serial data busses and can carry a variety of information over one or two wires (see Chapter 9). This signal technically becomes an input to the computer that is receiving the information.
- Informational input signals from a driver or passenger: These circuits may monitor a switch that the driver can operate on the instrument panel such as a trip or trip reset switch or a switch that requests AC operation or rear defogger operation. On modern vehicles, even horn buttons no longer energize the horn relay directly, but, instead, will simply make a request of a computer to energize the horn relay when the driver operates the switch.
- Informational input signals from a technician: A technician may talk to a computer in several different ways. On older vehicles, for example, he/she may ground a computer-monitored circuit to request diagnostic trouble codes or to request that some other diagnostic function be carried out. On modern

vehicles, the diagnostics are carried out, most often, through the technician connecting a scan tool that can talk directly to the on-board computers via binary code.

Outputs. Outputs are defined as circuits that allow the computer to make a change in the performance of a circuit or system. For example, the computer may energize a fuel pump relay with the ultimate goal of energizing the fuel pump itself, or it may energize a fuel injector or an AC compressor clutch. Because most output components are load components, their sole purpose is to turn electrical current flow into some type of work—heat, light, or electromagnetism. Therefore, these circuits tend to flow much higher current than an input circuit does. Output circuits include:

- Actuator circuits: These circuits allow the computer to control a light bulb (such as a warning light on the instrument panel or the interior courtesy lights), a heating grid (such as the rear window defogger or that found behind the glass of a heated mirror), or an electromagnetic device such as a relay, a motor (may be controlled via a relay or may be directly controlled depending on how much current the motor draws), or a solenoid (such as a door lock/unlock solenoid or a solenoid-operated valve such as a fuel injector).
- Informational output circuits to other computers: As explained earlier under “Informational Input Circuits from Other Computers,” computers share information with each other, either through dedicated signal wires or through serial data bus circuits. This signal technically becomes an output of the computer that is sending the information.
- Informational output signals to a driver or passenger: The computer, at times, will inform the driver of certain conditions, such as an indicator that reminds the driver that the rear defogger is turned on or a bulb on the instrument panel (malfunction indicator lamp) that will illuminate to tell the driver that the computer is aware that a problem exists within the system.
- Informational output signals to a technician: When a technician makes a request of the computer for diagnostic trouble codes, the computer will respond by talking back to the technician in some way. On older vehicles, the computer may flash the malfunction indicator lamp (check engine light), may flash an LED that is mounted on the computer itself, or may pulse voltage that can be monitored with an analog voltmeter so as to count code pulses. On modern vehicles, the computer communicates the same information and more via a scan tool through binary code.

Data Busses. When computers communicate with other control modules or control panels in the form of binary code or serial data, they communicate through circuits called *serial data busses* or *data links*. Some data busses transmit data in only one direction, although most transmit bi-directionally. What makes a data bus different from an ordinary circuit is that it is not dedicated to just one voltage signal, but can allow for communication of multiple messages. Chapter 9, “Multiplexing Concepts,” provides further discussion of this topic.

Logic Gates

Definition. Logic gates are defined as the programming circuitry within a digital computer that determines what output reaction to make in response to a given combination of input values. The CPU, therefore, does not actually “think,” but, rather, makes decisions based upon a combination of the input values and the information stored in the memory IC chips. The logic gates are sometimes referred to as the *logic circuits.*

Logic Gate Basic Construction. If two semiconductor materials placed back to back make up a diode and three semiconductor materials placed back to back make up a transistor (see Chapter 1), then more than three semiconductor materials placed back to back create *combinations of transistors* known as logic gates. Also, as described in Chapter 1, an NPN transistor requires a *positive* polarity applied to its base in order to become forward biased and complete the circuit it controls; we will now refer to this *positive* polarity as a binary *one*. And, likewise, a PNP transistor requires a *negative* polarity (or ground) applied to its base in order to become forward biased and complete the circuit it controls; we will now refer to this *negative* polarity as a binary *zero.*

It is also important to understand that all logic gates receive 5-V reference voltage from the computer's internal reference voltage regulator; this is the voltage that allows the logic gates to operate. This voltage signal is fed through a resistor and then to the logic gates. If this reference voltage is grounded out by an external switch (Figure 2–11), the voltage is pulled low—to zero volts.This represents a binary zero to the logic gates. But if the external switch is open and is not grounding out the reference voltage, then the logic gates receive a 5-V signal (Figure 2–12). This represents a binary one.

Finally, if the voltage applied to the computer is less than 9.6 V, the reference voltage regulator quits producing its 5-V output and the logic circuits no longer function properly. We will discuss this in more depth later.

The Need to Understand Logic Gates. Logic gates are the programming circuits in digital computers that began replacing analog computers in the automobile in the late 1970s. Today, digital computers are everywhere—from the automobile and heavy-duty diesel truck to the modern PC or laptop that you use to get your e-mail. The following explanation of logic gates is not given with the intent of training the reader to a level so as to be able to design and program computers. It is simply to take some of the magic out of the "magic box," as a computer is many times called. The student/technician who can visualize that an automotive computer makes decisions based on real electrical circuitry (okay, so they are microscopic circuits, but they are still real) will take a more efficient approach to diagnostics than many of his/her counterparts within the industry.

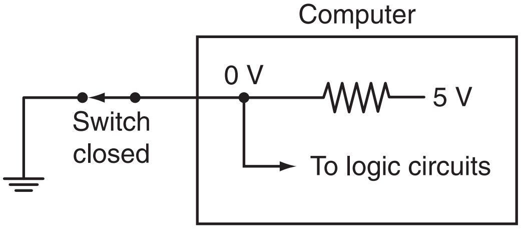


Figure 2–11 Grounding-type switch grounding out the reference voltage to the logic circuits—results in a binary zero.

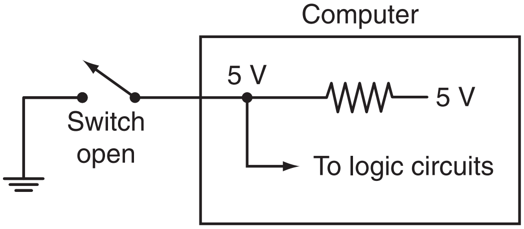


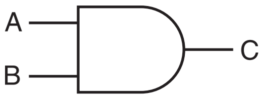
Figure 2–12 Grounding-type switch open, releasing the reference voltage from ground—results in a binary one.

Additionally, it is critical to understand the dependence that logic gates have on the reference voltage regulator, and, in turn, the dependence that the reference voltage regulator has on proper voltage and ground being supplied to the computer in order to reduce the chance of replacing a good computer at an unnecessary cost to you or your customer. (About 85 percent of computers that are replaced by technicians do not need to be replaced.)

Also, bear in mind that more and more computers are being added to the vehicle, with one manufacturer now having between 70 and 135 computers on board depending on how many features the vehicle is ordered from the factory with (of course, not all of these are major computers; rather, many of these are small computers having few inputs and controlling few outputs, but they still operate on the computer principles discussed in this book). Therefore, in the future, it will be increasingly important for the technician to have some understanding of how computers are designed to operate internally in order to better facilitate his/her diagnostic approach on today's electronic vehicles as well as those of tomorrow.

Basic Logic Gates. There exist three basic gates out of which all of the more complex gates are built—the *"AND" gate*, the *"OR" gate*, and the *"NOT" gate*. Let us discuss these three gates and then we will take a look at a simple computer schematic that uses them. Each gate has a symbol, a definition, and a truth table. Bear in mind that you will not find a physical component within a computer that looks like the symbol—it is simply a symbol that represents more complex circuitry. With the discussion of each gate, there is an electrical schematic that depicts what the gate accomplishes electrically.

AND Gate. An AND gate is depicted with the symbol shown in Figure 2–13. It has a flat input side with two inputs, A and B, and a curved output side with one output, C. An AND gate is defined as a gate in which the output, C, will be a binary one only when both inputs, A and B, are binary ones. The truth table in Figure 2–13 demonstrates the four possible combinations of the two inputs and the results. Figure 2–14 shows the more complex circuitry that an AND gate represents. It is like two switches in series—the only time that lightbulb C will light is when both transistors are forward biased (or when both transistors have a binary one applied to their bases).



A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

Figure 2–13 The symbol and truth table for an AND gate.

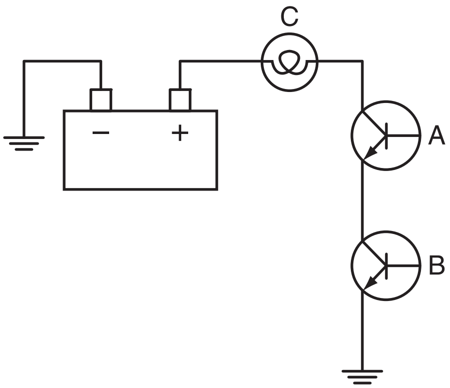
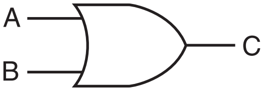


Figure 2–14 The circuitry represented by an AND gate.

A simple example of the use of an AND gate would be a motorized shoulder belt—only one input is typically required to move the belt off the occupant (to the "A" pillar). However, two inputs are typically required to move the belt back across the occupant (to the "B" pillar)—the door must be closed and the ignition switch must be turned to "run." If either one of these input conditions is not met, the belt will not move to the "B" pillar. An AND gate requires two conditions to be met before the computer will perform the assigned task.

OR Gate. An OR gate is depicted with the symbol shown in Figure 2–15. It has a concave input side with two inputs, A and B, and an output side that is curved and comes to a slight point with one output, C. An OR gate is defined as a gate in which the output, C, will be a binary one



A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

Figure 2–15 The symbol and truth table for an OR gate.

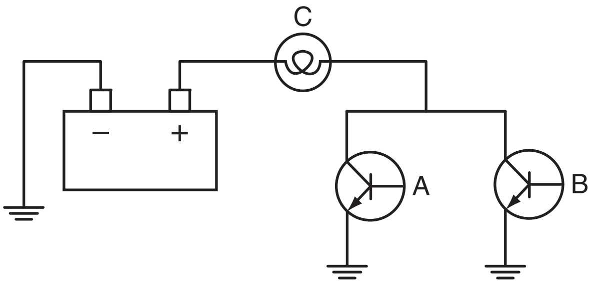
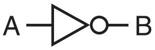


Figure 2–16 The circuitry represented by an OR gate.

when either input, A or B, is a binary one. The truth table in Figure 2–15 demonstrates the four possible combinations of the two inputs and the results. Figure 2–16 shows the more complex circuitry that an AND gate represents. It is like two switches in parallel—if either transistor is forward biased (or both), light bulb C will light (or when either transistor has a binary one applied to its base).

A simple example of the use of an OR gate would be a cruise control system that is currently engaged. The cruise control computer will disengage the system if the driver either steps on the brake pedal (thus activating the stoplamp switch) or if he/she presses the CANCEL switch. If either one of these input conditions is met, the computer will respond. An OR gate requires only one of two conditions to be met before the computer will perform the assigned task.

NOT Gate. A NOT gate is depicted with the symbol shown in Figure 2–17. It is shown as a triangle with a circle after it. It has a single input, A, and a single output, B. The triangle represents the input side and the circle represents the output side. It is actually an inverter in that it inverts whatever the input value is to the opposite value. As shown in the truth table in Figure 2–17, if the input is a binary zero, then the output is a binary one. And if the input is a binary one, then the output is a binary zero. Figure 2–18 shows the more complex circuitry that a NOT gate represents. When transistor A is turned off, 5 V is available to B. But when transistor A is forward biased (or has a binary one applied to its base), the voltage to B is grounded out and therefore reduced to zero volts (or a binary zero).



A	B
0	1
1	0

Figure 2–17 The symbol and truth table for a NOT gate.

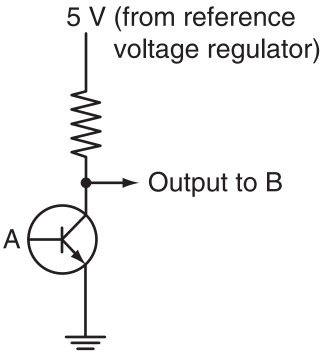


Figure 2–18 The circuitry represented by a NOT gate.

Basic Gates Example. Figure 2–19 shows a simple computer, using all three types of gates, which might be used to control an audible electronic chime underneath the instrument panel. The headlight switch, when turned on, sends a voltage of a positive polarity (a binary one) to an OR gate. When the ignition key is in the lock cylinder, it completes a path to ground, thus sending a signal of a negative polarity (a binary zero) to a NOT gate, which inverts it to a binary one and relays it to the OR gate. (When the key is *not* placed in the lock cylinder, no ground would be applied to this circuit; thus, reference voltage would not be pulled low, resulting in a binary one to the NOT gate, which would invert

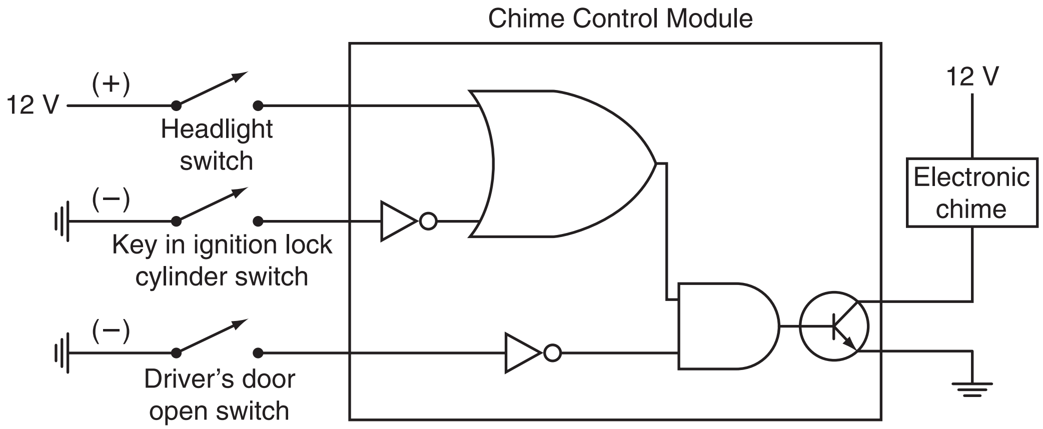


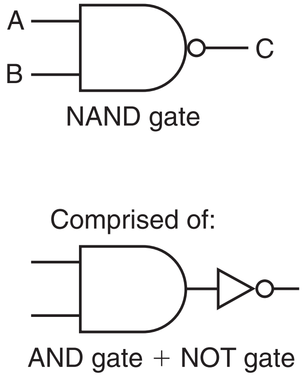
Figure 2–19 A schematic of a typical control module showing the internal logic gates.

it to a binary zero before relaying it to the OR gate.) If the OR gate receives a binary one from either source, it would send a binary one to the AND gate. If the driver's door is opened, the door open switch grounds the 5-V reference and sends a binary zero to a NOT gate, which inverts it to a binary one and relays it to the AND gate. If the AND gate receives a binary one on both inputs, it sends a binary one to the base of the NPN transistor. The transistor, in turn, applies a ground to the electronic chime, which then sounds audibly. Therefore, the combination of gates within this module would determine that if either the headlights are turned on *or* the key is in the ignition lock cylinder *and* the driver's door is also opened, then the chime would sound audibly to alert the driver. This example involves a simplistic computer, but it demonstrates how logic gates are used to determine the existence of the proper combination of input conditions prior to performing an output function. Most major computers in an automobile have tens of thousands of logic gates that provide for the computer's programming.

Other Logic Gates. There are other gates that are built out of the three basic gates already discussed. Some of these are shown as follows:

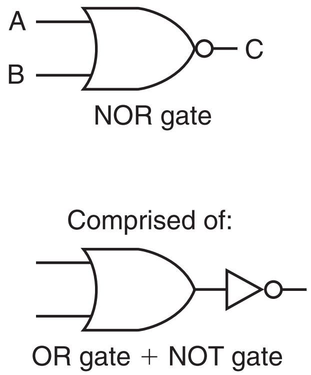
NAND Gate. A NAND gate is simply an AND gate with the inverter function of a NOT gate placed immediately after it. The symbol and truth table for a NAND gate are shown in Figure 2–20. The symbol is that of an AND gate with the circle from a NOT gate placed after it. Figure 2–20 also shows the basic gates that a NAND gate is comprised of.

NOR Gate. A NOR gate is simply an OR gate with the inverter function of a NOT gate placed immediately after it. The symbol and truth table



A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

Figure 2–20 NAND gate.

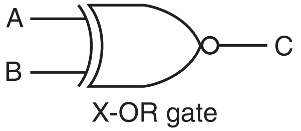


A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

Figure 2–21 NOR gate.

for a NOR gate are shown in Figure 2–21. The symbol is that of an OR gate with the circle from a NOT gate placed after it. Figure 2–21 also shows the basic gates that a NOR gate is comprised of.

Exclusive-OR (X-OR) Gate. An X-OR gate is a combination of gates that will produce a high output signal (a binary one) when the inputs are different from each other. The symbol and truth table for a NAND gate are shown in Figure 2–22. The symbol is that of an OR gate with an additional concave line ahead of it and the circle from a NOT gate placed after it. Figure 2–22 also shows that an X-OR gate is comprised of a combination of NAND gates.



A	B	C
0	0	0
0	1	1
1	0	1
1	1	0

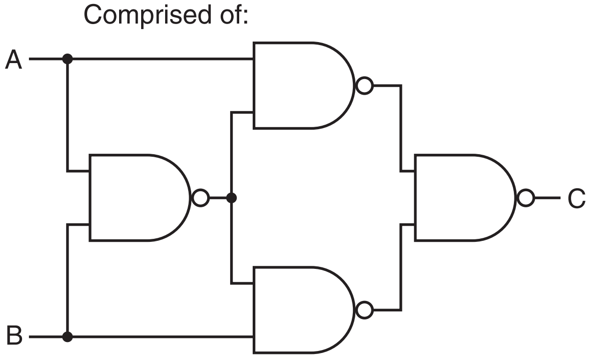


Figure 2–22 Exclusive-OR (X-OR) gate.

The Effect of Low Voltage on the Computer's Logic Gates

If the voltage applied to the computer is less than 9.6 V (or if the voltage drop across the computer becomes less than 9.6 V), the reference voltage regulator quits producing the 5-V signal that the logic gates (and some sensors) rely on, at which point the computer begins making wrong decisions or may even quit responding at all. This can happen due to a severely discharged battery, a battery that cannot hold a proper load when the starter motor is engaged, or excessive resistance in the computer's power and/or ground circuits. However, this can also be the result of a combination of some unwanted resistance in the computer's power and/or ground circuits, coupled with the fact that it is natural for the load of the starter to pull battery voltage low when attempting to start the engine. Restated, if the battery is fully charged at 12.6 V and there is excessive resistance in the power and/or ground circuits that is dropping another 2 V, the reference voltage regulator will still function at the remaining 10.6 V. But as soon as the ignition key turns and the starter is engaged, battery voltage is reduced another 2 V, typically to about 10.6 V. When coupled with the unwanted resistance, the remaining 8.6 V is not enough to allow the regulator to output its 5 V and the logic gates quit functioning. If you suspect this as a possibility when the computer does not seem to operate properly, test the battery's open circuit voltage and perform a load test. Then simply measure the voltage at a sensor that also receives this 5-V reference voltage (the throttle position sensor, for instance) with the ignition key turned to "run" and also while attempting to crank the starter. If the reference voltage is not correct, perform the appropriate voltage drop tests on the computer's power and ground circuits (discussed in Chapter 6). For this type of fault, replacing the computer will not help. The power and/or ground circuits must be properly diagnosed and repaired.

FUNCTIONS OF THE ENGINE COMPUTER

The engine computer, known today as the **powertrain control module (PCM),** controls (or may control) several different systems as discussed in the following pages.

Fuel Management

The PCM controls the amount of fuel being delivered to the engine in proportion to the volume of air that the engine is drawing in. This ultimately controls the air/fuel ratio. This was true of the early systems with electronically controlled feedback carburetors, and it remains true in modern fuel injection systems. The PCM's goal is to control the air/fuel ratio so as to produce the fewest exhaust emissions and the best fuel economy, and still provide the desired driveability.

During cold engine operation and heavy load conditions, as at wide-open throttle, the PCM adds fuel to the combustion chamber so as to create a rich air/fuel ratio for best driveability. During warm engine operation at light-to-moderate load, the PCM controls the fuel so as to maintain an air/fuel ratio of approximately 14.7:1 (14.7 parts air to one part fuel as measured by weight). This air/fuel ratio is commonly known as a **stoichiometric** air/fuel ratio. This air/fuel ratio provides for low emissions, good fuel economy, and still enough power for light or moderate load conditions. Many modern PCMs will run the air/fuel ratio even leaner than this under certain cruise conditions so as to improve fuel economy even further.

Idle Speed Control

In controlling the engine's idle speed electronically, a PCM can precisely control the idle speed so as to maintain the best compromise between a speed at which the engine is prone to stalling and one that wastes fuel and produces an annoying lurch as an automatic transmission is pulled into gear. It can also control idle speed so as to compensate for the load of the

Stoichiometry and 14.7 to 1

Keep in mind that a stoichiometric ratio is the one that most effectively allows all the components of the emissions control system, most notably the catalytic converter, to minimize exhaust emissions. When these systems were first invented, 14.7 to 1 was the ideal ratio for standard gasoline. Since that time, many changes have been made to fuels, including different blends for different seasons of the year, different altitudes, and even different areas, depending on their compliance with federal air quality standards. But while *oxygenated* and other special fuels have changed the numbers of the ratio somewhat, the objective remains the same: to maintain the fuel/air ratio so that the resulting exhaust emissions are kept at their optimal state.

Stoichiometric Air/Fuel Ratios

A stoichiometric air/fuel ratio provides just enough air and fuel for the most complete combustion, resulting in the smallest possible total amount of leftover combustible materials: oxygen, carbon, and hydrogen. This maximizes the production of CO_2 and H_2O and minimizes the potential for producing CO, HC, and NO_x. It also provides good driveability and economy.

The most power is obtained from an air/fuel ratio of about 12.5 to 1, although the best economy is obtained at a ratio of about 16 to 1.

Air/fuel ratios that are this far from stoichiometric, however, are not compatible with the three-way catalytic converter. The leaner mixtures also increase engine temperature as a result of slower burn rate.

air-conditioning clutch as it cycles on and off, as well as to compensate for the load of the power steering pump in a parking situation. It can also adjust idle speed in an effort to compensate for low charging system voltage, low engine temperature, and engine overheating.

Electronic Ignition Timing

Ignition timing is well known to be a major factor in both fuel economy and driveability. It is also a critical factor in the control of exhaust emissions. With the PCM in control of the ignition timing, timing does not have to be dependent on engine speed and load alone. It can be adjusted to meet the greatest need during any driving condition. For example, following a cold start, it can be advanced for driveability. During light load operation with a partially warmed-up engine, it can be retarded slightly to hasten engine warm-up and reduce exhaust emissions. During acceleration or wide-open throttle (WOT) operation, it can be adjusted for maximum torque.

Emission Systems

The PCM influences and/or controls several emission systems. For example, the ability of the PCM to control the air/fuel ratio to a stoichiometric value allows the catalytic converter to perform its job much more efficiently. And the PCM also plays a direct role in controlling other emission systems, including the secondary air injection system, the EGR system, the evaporative/canister purge system, and others. See Chapter 4 for a further discussion of emission systems.

Torque Converter Clutch Control

In an automatic transmission, most PCMs control a clutch in the torque converter, whether or not the transmission is fully electronic. This function eliminates converter slippage and heat production and thus contributes to fuel economy when the vehicle is under cruise conditions.

Electronic Automatic Transmission Control

In most modern applications, the PCM controls the upshifts and downshifts of the automatic transmission. The valve body is now under the PCM's control. The PCM uses throttle position and vehicle speed in order to precisely control the shift points.

Transmission Upshift Light

In some manual transmission applications, the computer activates an upshift light, which alerts the driver when to upshift to obtain maximum fuel economy.

Air-Conditioning Control

Some computerized engine control systems feature an air-conditioning clutch cut-out function that is controlled by the PCM. The PCM disengages the air-conditioning clutch during wide-open throttle operation. This function contributes to driveability under heavy load conditions. In some systems, the PCM may also disengage the A/C clutch when power steering pressure is high, as when turning into a parking space, so as to avoid engine stall.

Turbocharger Boost Control

To increase performance, many manufacturers offer a turbocharged engine option. In most cases, the computer controls the amount of boost that the turbocharger can develop. Many manufacturers use an air-to-air intercooler on selected turbo applications. This lowers manifold air temperature by 120°F–150°F and allows for even more aggressive turbo boost and spark advance due to the denser air charge.

Speed Control

Many PCMs also have the added responsibility of controlling the vehicle speed control (cruise control) function. While many early electronic speed control systems were controlled by dedicated control modules, today they are more often controlled by one of the more major computers, most often the PCM.

CONTROLLING EXHAUST GASSES

The computer of a computerized engine control system has a mission: to reduce emissions, improve fuel mileage, and maintain good driveability. The priority varies, however, under certain driving conditions. For example, during warm-up, driveability has a higher priority than mileage, and at full throttle the computer will give the performance aspect of driveability a higher priority than emissions or mileage.

The Seven Exhaust Gasses

There are seven major exhaust gasses that exit from an automobile's tailpipe: nitrogen (N_2), oxygen (O_2), hydrocarbons (HC), water vapor (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), and oxides of nitrogen (NO_x).

1. *N_2:* Nitrogen makes up about 78 percent of atmospheric air. Most of the nitrogen in the air simply goes through the engine unchanged and exits the tailpipe as nitrogen.
2. *O_2:* Oxygen forms the basis for all combustion. It constitutes about 21 percent of our air and is the element that supports all flame. The burning of oxygen and fuel releases the chemical energy that does all the work of the engine and the vehicle. A properly operating feedback control system results in a slightly fluctuating amount of residual oxygen in the exhaust. A very rich mixture would have so much fuel that all the oxygen would be consumed; a very lean mixture would leave too much oxygen unused in the exhaust.
3. *HC:* Gasoline is a hydrocarbon compound, as is engine oil. When hydrocarbons burn properly, the hydrogen and carbon atoms separate; each combines with oxygen to form either water (H_2O) or carbon dioxide (CO_2). If for any reason the gasoline in the cylinder fails to burn, it is pumped into the exhaust system as a raw HC molecule, a most undesirable emissions result. Hydrocarbons may also be emitted to the atmosphere by reason of simple evaporation, as would happen if the gas cap were not properly reinstalled after refueling.
4. *H_2O:* Water vapor forms the bulk of the exhaust product of most engines, even those running very poorly. The major source of energy in the fuel is the hydrogen, which readily combines chemically with the atmospheric oxygen drawn in with the intake air, releasing heat energy and forming water vapor. This is the most benign product of the engine's combustion, and it is of concern only if the engine is run so little that condensed water is left on the interior surfaces or in the exhaust system, providing a favorable environment for rust.
5. *CO_2:* Carbon dioxide forms in the burning of the carbon portion of the fuel. Carbon dioxide is a harmless portion of the exhaust. It is the same gas used by plants in the respiration cycle, and it is the same gas used to carbonate beverages. While some carbon dioxide is harmless, environmental concerns have focused recently on the sheer amount of the gas produced by internal combustion engines. Some people have expressed fears that a significant increase in the level of atmospheric carbon dioxide could have a "greenhouse effect" on the Earth's atmosphere, eventually changing the climate.
6. *CO:* Carbon monoxide is a very deadly and poisonous gas, odorless and colorless, and lethal in almost undetectably small concentrations. During normal combustion, each carbon atom tries to take on two oxygen atoms (CO_2). If, however, there is a deficiency of oxygen in the combustion chamber, some carbon atoms are only able to combine with one oxygen atom and thus produce CO. The carbon monoxide actively tries to obtain another oxygen atom wherever it can find

Other Exhaust Emissions from Gasoline Engines

Aldehydes
Ammonia
Carboxylic acids
Inorganic solids
  lead (from leaded fuel)
  soot
Sulfur oxides (from fuel impurities)

one, and this oxygen-scavenging property of CO is what makes it so lethal. If breathed into the lungs, it not only provides no oxygen, it removes what oxygen it finds there. An overly rich air/fuel ratio is the only cause of CO production.

7. *NO_x:* Air is made up of about 78 percent nitrogen and 21 percent oxygen. Under normal conditions, nitrogen and oxygen do not chemically unite. When raised to a high enough temperature, however, they unite to form a nitrogen oxide compound, NO or NO_2. These compounds are grouped into a family of compounds referred to as oxides of nitrogen: NO_x. Oxides of nitrogen start to form at about 2500°F, with production increasing as temperatures go higher.

Catalytic Converter

The catalytic converter is the single most effective emissions control device on the modern automobile. The catalytic converter's role in controlling exhaust emissions is directly affected by the PCM's ability to properly control the air/fuel ratio. Because the catalytic converter needs a stoichiometric air/fuel ratio or richer to reduce NO_x emissions back to nitrogen and oxygen (Figure 2–23), and because it also needs a stoichiometric air/fuel ratio or leaner in order to oxidize hydrocarbon and carbon monoxide emissions, the ability of the PCM to hold the air/fuel ratio close to stoichiometric improves the efficiency of the catalytic converter. Figure 2–24 also shows how the efficiency level of the catalytic converters is affected by changes in the air/fuel ratio.

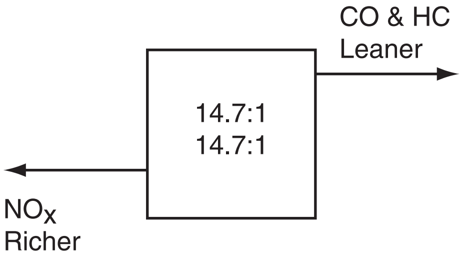


Figure 2–23 Three-way catalytic converter air/fuel ratio requirements.

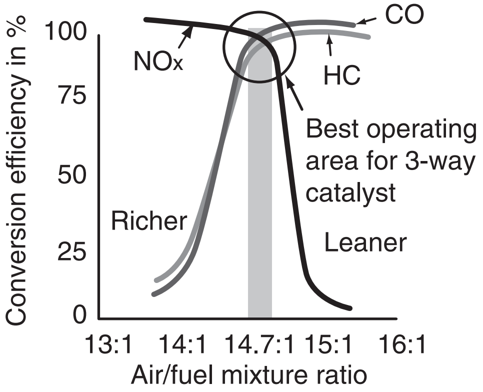


Figure 2–24 Catalytic converter efficiency.

CLOSED LOOP AND OPEN LOOP OPERATION

Closed Loop Operation

Made possible by the development and use of the oxygen sensor, a feature of all comprehensive computerized engine control systems is the ability to operate the engine in a closed-loop mode. The term **closed loop** refers to the fact that the engine computer *monitors the results of its own control* through a feedback circuit. With the use of a feedback circuit, a computer is able to monitor what actually happened as a result of the last command it issued to an actuator. Without a feedback circuit, the computer must *assume* that it is controlling the actuator properly and that the actuator is responding properly. As computer technology has moved forward, increasing numbers of output circuits have been monitored with feedback circuits and sensors.

In engine control systems, "closed loop" refers to the use of the oxygen sensor as it is used to monitor the results of the last commands issued to the fuel injector(s) (or mixture control solenoid in a feedback carburetor). Closed loop is a mode that allows the engine computer to maintain an air/fuel ratio that stays very close to stoichiometric. When operating in closed loop, the engine computer responds to the other critical sensors in bringing the air/fuel ratio close to the ideal. These sensors include throttle position, engine load, barometric pressure, engine RPM, engine coolant temperature, and intake air temperature. Then the engine computer uses the oxygen sensor to fine-tune the air/fuel ratio. The oxygen sensor reports to the computer a voltage representing the amount of oxygen that was left over after the burn during the most recent combustion. The computer sends a command to the fuel-metering control device to adjust the air/fuel ratio toward a stoichiometric air/fuel ratio (14.7 to 1). This adjustment usually causes the air/fuel ratio to cross stoichiometric, and it starts to move away from 14.7 in the opposite direction. The oxygen sensor sees this and reports it to the computer. The computer again issues a command to adjust back toward 14.7 to 1. With the speed at which this cycle occurs, the air/fuel ratio never gets very far from 14.7 to 1 in either direction. This cycle repeats continuously.

Closed loop is the most efficient operating mode, and the computer is programmed to keep the system in closed loop as much as possible. However, the following criteria must be met before the system will go into closed loop control:

- The oxygen sensor must reach operating temperature, around 315°C/600°F.
    - o Newer vehicles use a heater to bring the oxygen sensor up to its operating temperature more quickly at engine start-up. This allows the engine to get into closed loop control more quickly following a cold engine start.
- The engine coolant temperature must reach a criterion temperature.
    - o This varies somewhat but tends to be around 65°C/150°F to 82°C/180°F on older vehicles.
    - o On newer vehicles, this may be as low as 0°C/32°F, which allows the engine to get into closed loop control more quickly following a cold engine start. This also effectively removes the engine coolant sensor as a requirement for closed loop operation except on cold days during the winter months.
- A predetermined amount of time must elapse from the time the engine was started
    - o This varies from 1 or 2 minutes on some older vehicles to 10 to 20 seconds on most modern vehicles.

Ultimately, closed loop operation, using feedback information from the oxygen sensor to more precisely control the air/fuel ratio, is no longer reserved for warm engine operation as it once was. Manufacturers are now programming the computers to put the system into closed loop operation more quickly following a cold engine start so as to reduce cold engine exhaust emissions substantially. (Cold engine operation has always been considered a "dirty" operating mode that creates substantial excessive exhaust emissions.)

Because closed loop operation attempts to maintain a stoichiometric air/fuel ratio, an operating condition such as hard acceleration forces the system out of closed loop due to the fact that it needs a richer air/fuel ratio than closed loop can offer.

Open Loop Operation

Open loop operation is used during periods of time when a stoichiometric air/fuel ratio is not appropriate, such as cold engine warm-up (see "Closed Loop Operation") or at WOT. Open loop operation is also implemented during limp-in mode operation when a critical sensor has been lost. During this operational mode, the computer uses input information from several sensors to determine what the air/fuel ratio should be. These sensors may include throttle position, engine load, barometric pressure, engine RPM, engine coolant temperature, and intake air temperature.

Once the necessary information is processed, the computer sends the appropriate command to the mixture control device. The command does not change until one of the inputs changes. In this mode, the computer does not use oxygen sensor input and therefore does not know if the command it sent actually achieved the most appropriate air/fuel ratio for the prevailing operating conditions.

THE PCM AND EXHAUST EMISSIONS

The PCM uses closed loop control to achieve a stoichiometric air/fuel ratio for two primary reasons:

1. At this air/fuel ratio, the engine produces the smallest amount of toxic exhaust emissions (CO, HC, and NO_x) and maximizes the production of non-toxic emissions (H_2O and CO_2) within the combustion chamber.
2. At this air/fuel ratio, the catalytic converter, which is the single most effective emissions control device, operates at its peak efficiency, thereby further reducing exhaust emissions.

ATTITUDE OF THE TECHNICIAN

Historically, many automotive technicians have had a negative attitude about manufacturers' continuous changes to cars. Changes mean always having to learn something new, having to cope with a new procedure, and so on. There is no doubt that these changes will continue to be a challenge to technicians. But there is another way to look at it: Every time new knowledge or a new skill is required, it represents a new opportunity to get ahead of the pack. Most of us are in this business to make money; the more you know that other people have not yet bothered to learn, the more money you can make. Successful, highly paid automotive technicians *earn* the money they get because of what they *know*. Their knowledge enables them to produce more with equal effort. More importantly, it enables them to do things that other people cannot do. Therefore, it is becoming increasingly important to pursue this knowledge, both through textbooks such as this one and through technical classes as they are offered in your area.

Computerized automotive control systems represent the newest and probably the most significant and most complicated development ever to occur in the history of automotive service. (It is complicated, not because it is more difficult but because it involves more processes.) We have seen only the beginning. In recent years, every major component and function of the automobile has come under the control of an electronic control module, and engineers will undoubtedly continue to find new ways to use electronic control as we move forward. Those who appreciate the capability of these systems and learn everything they can about them will be able to service them and do very well while other people scratch their heads and complain.

✔ SYSTEM DIAGNOSIS AND SERVICE

Approaching Diagnosis

Diagnosing problems on complicated electronic systems takes a different approach than many automotive technicians are used to. The flat-rate pay system has encouraged many of us to take shortcuts whenever possible; however, shortcuts on these systems get you into trouble. Use the service manual and follow the procedures carefully. It is very useful to spend some time familiarizing yourself with the diagnostic guides and charts that manufacturers present in the service manuals you will be using.

Pre-Diagnostic Inspection. Although most computerized engine control systems feature some self-diagnostic capability, most do not directly monitor many physical aspects of the engine's support systems. Depending upon the system and its diagnostic abilities, non-monitored components may include spark plugs, spark plug wires, valves, vacuum hoses, PCV valves, and other engine support and emission-control components that are not a part of the computer system. A seemingly unrelated part, such as a spark plug wire, can have a direct impact on the performance of the system. For example, a shorted spark plug wire prevents its cylinder from firing. The unburned oxygen coming out of that cylinder, if it is on the same side as the oxygen sensor on a V-type engine, causes the oxygen sensor to mistakenly see a lean condition. The computer responds by enriching the air/fuel mixture. Replacing the oxygen sensor, half or all of the other sensors, the computer, the headlights, and the front bumper does not solve the problem. Replacing the shorted spark plug wire and possibly cleaning the spark plug *does* solve the problem.

The computer knows the engine-operating parameters (throttle position, atmospheric pressure, engine speed, engine load, coolant temperature, etc.), and with this information it can calculate exactly what the spark timing should be. It continuously makes calculations and sends its spark timing commands. It does not, however, know what base timing is (except on models where the base timing is fixed and cannot be readjusted); and the command it sends out is added to base timing. If base timing is incorrect, a spark plug will fire at the wrong time in spite of the computer.

Having a thermostat stuck closed or a restricted radiator causes the engine to overheat, possibly causing the computer to think that the coolant temperature-sensing device or its connecting circuit is shorted and setting a fault code in its diagnostic memory. The coolant sensing device, however, is only reporting what it sees; the fault is in the cooling system. Do not overlook the possibility that someone has replaced a 195°F thermostat with one that opens at 160°F, or that the charcoal canister is saturated with gasoline, or that it is being purged when it should not be. Do not overlook the possibility of loose or shorted electrical wires or of cracked or misrouted vacuum hoses.

Any such problem, although it may not be directly related to the computer system, can cause a driveability problem and can in some cases cause the computer to report a problem in one of its circuits. The service manual for each vehicle with an engine control computer system should provide instructions for making a pre-diagnostic inspection, because the system's diagnostic procedures assume that all such unrelated (or perhaps it would be better to say *semi-related*) systems are functioning properly. All of the engine components, especially engine support components, and some non-engine components such as the transmission, are more related in their influence on each other than they ever were before the development of computer control systems. It is extremely important to remember that for the computer control system to work properly, all other engine-related systems must be operating to manufacturer's specifications. If routine maintenance, such as changing the oil, PCV valve, spark plugs, and spark plug wires, is due, it is advisable to do it before beginning diagnostic procedures.

SUMMARY

In this chapter, we have begun building a conceptual foundation for understanding why vehicle manufacturers use computers in their vehicles and what the computers are supposed to do. The principal design objectives are to control exhaust emissions to a legally acceptable level, to optimize the vehicle's driveability, and to get the best fuel economy consistent with the driving conditions.

We have learned about the major components of a computer, including the microprocessor as the central element of the engine control computer. We also discussed the various types of memories and how they are used in an engine computer. We covered the digital voltage signals, known as binary code or serial data, which a computer uses to communicate internally and externally. And we took an in-depth look at logic gates, or combinations of transistors, that allow the computer to respond appropriately to particular combinations of input values.

We have learned about the various elements in a car's exhaust that are toxic: hydrocarbons (or unburned fuel), carbon monoxide, and oxides of nitrogen. We have seen how residual oxygen is used as a measure of the computer's mixture control success and how even water vapor and carbon dioxide are produced as a result of the hydrogen and carbon in the fuel.

The concept of stoichiometry has been introduced, a concept that will play a role in each successive chapter. A stoichiometric air/fuel ratio not only allows the engine to produce the fewest toxic emissions, but also allows the catalytic converter to keep emissions to a minimum. The only way to accurately maintain this ratio is through the precision control of a computer.

We have learned the concepts of open loop and closed loop. Open loop describes the conditions under which the computer determines air/fuel mixture and ignition timing based on information stored in its memory about engine temperature, engine load, engine speed, and other system parameters. Closed loop, in contrast, is the feedback mode in which the computer controls air/fuel mixture by adding in the output signal from the oxygen sensor.

Finally, we have learned the importance of following precise diagnostic steps if this type of computer system is to be diagnosed. Without such a sequence, the technician can be misled by other problems or by countermeasures the computer employs to solve some other problem that has affected the system.

Excessive HC Production

Over-advancing ignition timing by 6 degrees can cause HC production to go up by as much as 25 percent and NO_x production to increase by as much as 20 to 30 percent. A thermostat that opens at 160°F can cause HC production to go up as much as 100 to 200 parts per million.

▲ DIAGNOSTIC EXERCISE

In an uninformed and socially irresponsible attempt to improve his car's performance, a do-it-yourselfer disconnected, disabled, or removed most of the emissions controls on his car. He blocked off the EGR and disconnected most of the vacuum lines.

What will the consequences be for the car? Will its driveability, power, or fuel economy improve? What should the repair/diagnostic technician's approach be?

Review Questions

1. Technician A says that computerized engine control systems are intended to reduce exhaust emissions. Technician B says that computerized engine control systems are designed to improve fuel mileage and driveability. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. Two technicians are discussing why computers have replaced mechanical control methods for controlling both engine management

systems and non-engine systems. Technician A says that computers are able to provide more precise control, faster response, and increased dependability as compared to mechanical methods of control. Technician B says that computers provide the potential to add additional features and functions and also offer increased diagnostic capabilities. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
3. An analog voltage is a voltage signal that does which of the following?
   A. It is continuously variable within a given range and requires time to change.
   B. It varies, but not continuously, and requires no time to change.
   C. It is often referred to as a square wave.
   D. Both B and C
4. A digital voltage is a voltage signal that does which of the following?
   A. It is continuously variable within a given range and requires time to change.
   B. It varies, but not continuously, and requires no time to change.
   C. It is often referred to as a square wave.
   D. Both B and C
5. How many combinations of zeros and ones are available to an 8-bit computer?
   A. 64
   B. 128
   C. 256
   D. 65,536
6. The binary code 01101110 equals what decimal (base-10) numerical value?
   A. 5
   B. 110
   C. 124
   D. 421
7. How many combinations of zeros and ones are available to a 16-bit computer?
   A. 64
   B. 128
   C. 256
   D. 65,536
8. Which of the following components in an engine computer is a nonvolatile memory that contains information specific to a particular vehicle or model?
   A. A/D converter
   B. ROM
   C. RAM
   D. PROM
9. Which of the following components in an engine computer translates analog input signals to binary code?
   A. A/D converter
   B. ROM
   C. RAM
   D. PROM
10. Which of the following components in an engine computer is a volatile memory used by the microprocessor to store temporary information?
    A. A/D converter
    B. ROM
    C. RAM
    D. PROM
11. Concerning an AND gate, which of the following would cause the output (C) to be a binary one?
    A. When input A is a binary zero and input B is a binary one
    B. When input A is a binary one and input B is a binary zero
    C. When both inputs, A and B, are binary one
    D. All of the above
12. Concerning an OR gate, which of the following would cause the output (C) to be a binary one?
    A. When input A is a binary zero and input B is a binary one
    B. When input A is a binary one and input B is a binary zero
    C. When both inputs, A and B, are binary one
    D. All of the above

13. Which of the following could cause the reference voltage regulator and the logic gates within a computer to function improperly or not at all?
    A. Low battery voltage
    B. Battery does not hold a proper load when the starter motor is engaged
    C. Excessive resistance within the computer's power and/or ground circuits
    D. All of the above
14. What air/fuel ratio is required to allow a three-way catalytic converter to work effectively?
    A. 12:1
    B. 13.7:1
    C. 14.7:1
    D. 17:1
15. Why does the PCM attempt to maintain a stoichiometric air/fuel ratio?
    A. To minimize the potential for producing toxic emissions (CO, HC, and NO_x) in the combustion chamber.
    B. To maximize the production of H_2O and CO_2 in the combustion chamber.
    C. To help the three-way catalytic converter work most effectively.
    D. All of the above
16. Technician A says that any time a computer begins making incorrect decisions and starts controlling a system improperly, it should automatically be replaced. Technician B says that if a computer begins making incorrect decisions and starts controlling a system improperly, replacing the computer may not be the appropriate repair. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
17. Technician A says that closed-loop operation is designed to allow the engine computer to monitor the results of its own fuel control through an oxygen sensor mounted in the exhaust stream. Technician B says that closed loop is the best engine-operating mode for wide-open throttle performance because of the increased precision that closed loop provides. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
18. Closed-loop operation requires all except which of the following?
    A. The oxygen sensor must reach operating temperature.
    B. The engine coolant temperature must be at or above a criterion temperature.
    C. The vehicle speed must be at least 20 mph.
    D. A predetermined amount of time must have elapsed since the engine was started.
19. Technician A says that the continued changes in automotive design are a challenge to every technician. Technician B says that if you pursue learning through the reading of textbooks and through taking technical classes, new technology can become your advantage. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
20. Technician A says that a fault code indicating a coolant temperature sensor problem could be the fault of a defective coolant-temperature sensor or its circuit. Technician B says that a fault code indicating a coolant temperature sensor problem could be the result of a defective thermostat in the engine cooling system. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

Chapter 3

Common Components for Computerized Engine Control Systems

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Define the features common to most computerized engine control systems.
- ☐ Explain the functional concepts of each of the most common sensing devices.
- ☐ Understand the differences between a speed density system and a mass air flow system.
- ☐ Explain the operation of the most common types of actuators: solenoids, relays, motors, and stepper motors.
- ☐ Define how a computer's control of an actuator's on-time through pulse-width modulation differs from duty cycle control.

KEY TERMS

Actuator
Barometric Pressure
Duty Cycle
E-Cell
Gallium Arsenate Crystal
Hall Effect Switch
Hertz (Hz)
Impedance
Light-Emitting Diode (LED)
Piezoelectric
Piezoresistive
Potentiometer
Potentiometer Sweep Test
Schmitt Trigger
Sensor
Speed Density Formula
Stepper Motor
Thermistor
Volumetric Efficiency (VE)
Wide-Open Throttle (WOT)
Zirconium Dioxide (ZrO_2)

Among the different car manufacturers, vehicle models, and model years, there are many different computerized engine control systems. Although there are significant differences among the various systems, when compared, they are actually more alike than they are different. Some of the more common components and circuits are discussed in this chapter to avoid needless duplication when discussing the specific systems. As you read the following chapters, you may find it useful to refer to this chapter to clarify how a particular component or circuit works.

COMMON FEATURES

Computers

The comprehensive automotive engine computer (known as the powertrain control module [PCM]) is a special-purpose, small, highly reliable, solid-state digital computer protected inside a metal box. It receives information in the form of voltage signals from several **sensors** and other input sources. With this information, which the PCM rereads several thousand times per second, it can make "decisions" about engine calibration functions such as air/fuel mixture, spark timing, exhaust gas recirculation (EGR) application, and so forth.

These decisions appear as commands sent to the **actuators**—the solenoids, relays, and motors that carry out the output commands of the PCM. Commands usually amount simply to turning an actuator on or off. In most cases, the ignition switch provides voltage to the actuators either directly or through a relay. The PCM controls the actuator by using one of its internal solid-state switches (power transistors and quad drivers are two types) to ground the actuator's circuit. Whereas in most actuator circuits the PCM completes the actuator's ground side, occasionally the PCM may be circuited to complete the power side. If the wire that completes the circuit between the actuator and the PCM were to short to the engine block or to chassis ground and the PCM was providing power to the actuator, this short would likely destroy the PCM (Figure 3–1). But if the PCM uses this circuit to complete the actuator's ground path, a short to ground would not overload the PCM's circuits. However, it would keep the actuator energized (Figure 3–2). In certain instances where safety would be compromised by a short that could energize the actuator, the PCM may be circuited to provide power to the actuator.

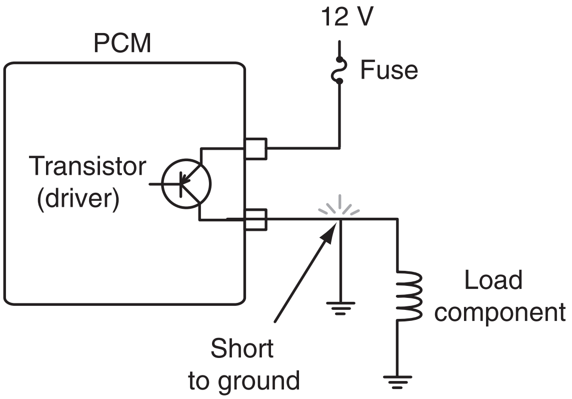


Figure 3–1 Computer providing power to an actuator. A short to ground can destroy the computer's driver.

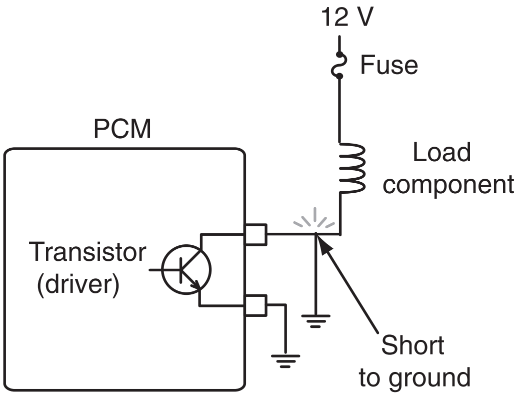


Figure 3–2 Computer completing an actuator's ground circuit. A short to ground keeps the actuator energized but does not overload the computer.

Also, the PCM may be circuited to complete both the power and ground circuits when it needs to be able to reverse the circuit's polarity. Examples include reversible DC motors and the windings of many **stepper motors.** (See "H-Gate" in Chapter 1.)

CAUTION: No attempt should be made to open a computer's housing. The housing protects the computer from static electricity. Opening it or removing any circuit boards from it outside carefully controlled laboratory conditions will likely result in damage to some of its components. Certain late-model systems use computers with a special kind of memory that can be reprogrammed by exposing that component to light, usually by removing a piece of opaque tape. If you do not intend to do such reprogramming, or you do not know what the effect will be, do not open a computer just to see what the internal parts look like. Over time, a technician can expect to find a completely failed computer that can be opened up without doing any additional harm.

PCM Location. Over the years, most manufacturers have located the engine computer within the passenger compartment rather than in the engine compartment. It is sometimes mounted under the instrument panel, behind either kick panel or under a front seat. This placement helps to protect it from the harsh environment of the engine compartment with its extreme temperature changes. Other manufacturers, such as with Chrysler's systems, Ford's early Microprocessor Control Unit (MCU) system, and modern General Motors systems, located it in the engine compartment. These computer cases are designed to protect the computer from the engine compartment's environment. In fact, late-model Chrysler engine computers have cases that also shield the computer's internal electronics from radio frequency interference (RFI) and electromagnetic frequency interference (EFI). Many engine computers are located on the passenger compartment side of the firewall under the instrument panel and attach to a harness connector on the engine compartment side of the firewall. Some manufacturers are now mounting the engine computer on the engine block, a concept that originated in the heavy-duty industry where the computer is matched to the engine rather than to the vehicle.

Engine Calibration. Because of the wide range of vehicle sizes and weights, engine and transmission options, axle ratios, and so forth, and because many of the decisions the computer makes must be adjusted for those variables, the manufacturers use some type of engine calibration unit (Figure 3–3). The calibration unit is a chip that contains information that has to be specific to each vehicle. For example, the vehicle's weight affects the load on the engine, so in order to optimize ignition timing, ignition timing calibration must be programmed for that vehicle's weight. In a given

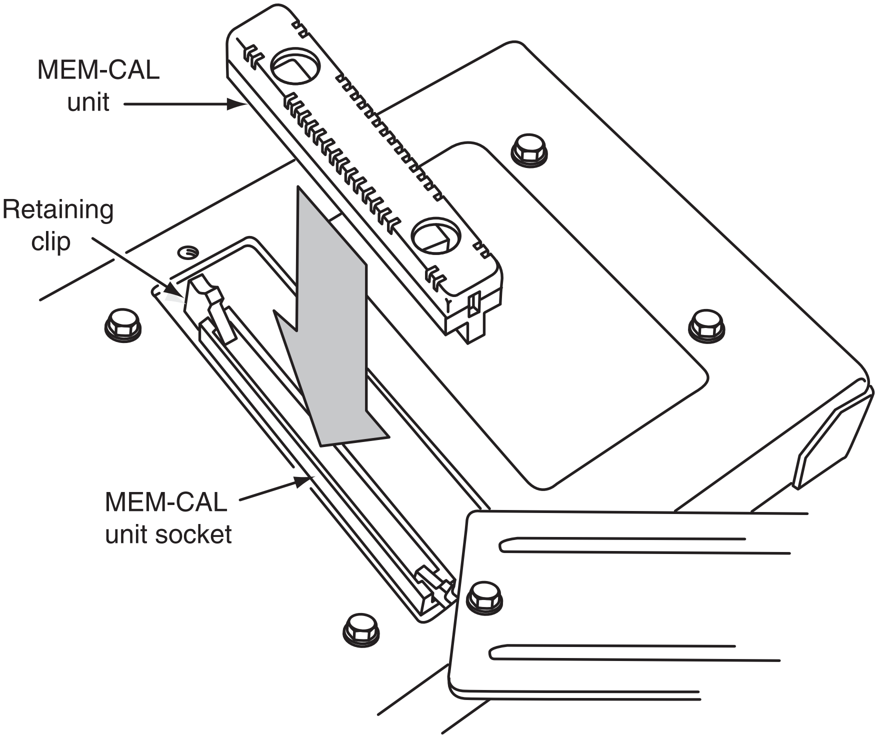


Figure 3–3 General Motors electronic control module and PROM.

model year, a manufacturer might have more than a hundred different vehicle models, counting different engine and transmission options, but might use fewer than a dozen different computers. This is made possible by using an engine calibration unit specific to each vehicle.

The engine calibration unit may be referred to as the "PROM," or some other term may be used. Some manufacturers make the calibration unit removable, and some make it a permanent part of the computer.

5-V Reference

With few exceptions, most manufacturers use a 5-V reference voltage from the PCM, which is sent to the sensors that require a reference in order to operate. (Some late 1970s and early 1980s systems used a 9-V reference.) Within the electronics industry, 5 V has been almost universally adopted as a standard for information-transmitting circuits. This voltage value is high enough to provide reliable transmission and low enough not to damage the tiny circuits on the chips in the computer. Of course, use of a computer-industry standard voltage makes parts specification more economical for the car makers.

SENSING DEVICES

Exhaust Oxygen Sensors

One of the major components of all comprehensive computerized engine control systems is the oxygen (O_2) sensor (Figure 3–4). The O_2 sensor, which is sometimes also referred to as the exhaust gas oxygen (EGO) sensor, measures the amount of free oxygen in the exhaust stream. This free oxygen, in turn, is a direct result of the air/fuel ratio. A rich mixture yields little free oxygen; most of it is consumed during combustion. A lean mixture, on the other hand, yields considerable free oxygen because not all of the oxygen is consumed during combustion. With an oxygen sensor in or near the exhaust manifold, measuring the amount of oxygen in the exhaust indirectly reveals the air/fuel ratio burned in the cylinder.

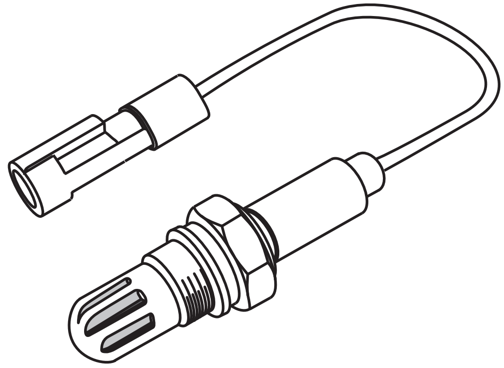


Figure 3–4 Oxygen sensor.

The heart of an oxygen sensor (Figure 3–5) is a hollow ceramic body that is closed at one end and contains within it a substance known as **zirconium dioxide (ZrO_2),** a white crystalline compound that becomes oxygen-ion conductive at approximately 600°F. The inner and outer surfaces of the ceramic body are coated with separate, super-thin, gas-permeable films of platinum. The platinum coatings serve as electrodes. The outer electrode surface is covered with a thin, porous ceramic layer to protect against contamination from combustion residue. This body is placed in a metal shell similar to a spark plug shell except that the shell has a louvered nose that encloses the exhaust-side end of the ceramic body. When the shell is screwed into the exhaust pipe or manifold, the louvered end extends into the exhaust passage. The outer electrode surface contacts the shell; the inner electrode connects to a wire that goes to the computer. Ambient oxygen is allowed to flow into the hollow ceramic body and to contact the inner electrode.

The oxygen sensor has an operating temperature range of 572°F to 1562°F (300°C to 850°C). When the zirconium dioxide reaches 572°F, it becomes oxygen-ion conductive. If the oxygen in the exhaust stream is less than that in the ambient air, a voltage is generated. The greater the difference, the higher the

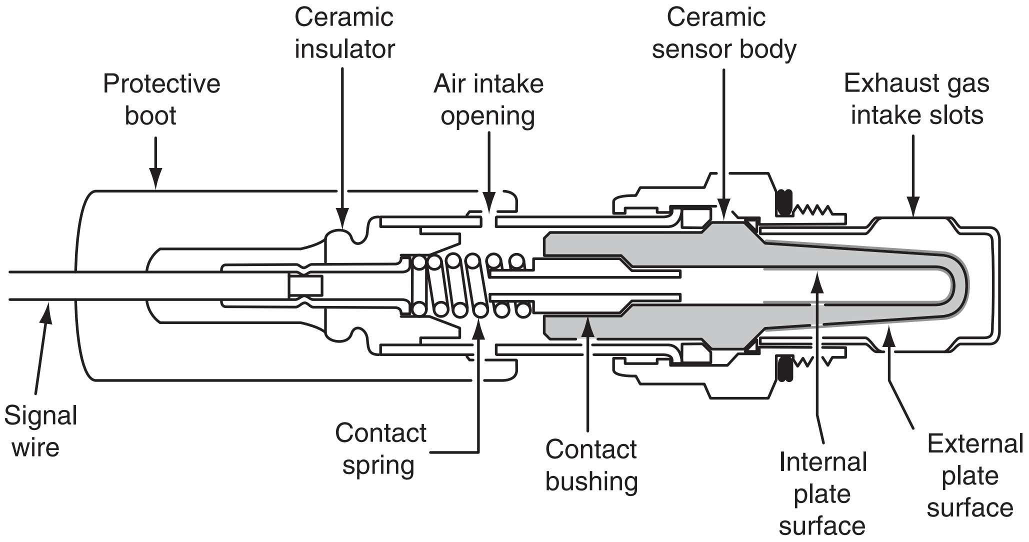


Figure 3–5 Exhaust gas oxygen sensor.

voltage signal generated (Figure 3–6). Voltage generated by the oxygen sensor will normally range from a minimum of 0.1 V (100 mV) to a maximum of 0.9 V (900 mV). The computer has a preprogrammed value, called a *set-point,* that it wants to see from the oxygen sensor during closed-loop operation. The set-point is usually between 0.45 V and 0.5 V and equates to the desired air/fuel ratio. Voltage values below the set-point are interpreted as lean (the percentage of oxygen in the exhaust stream and in the ambient air becomes closer), and values above it are interpreted as rich (percentages of oxygen in the two areas move apart).

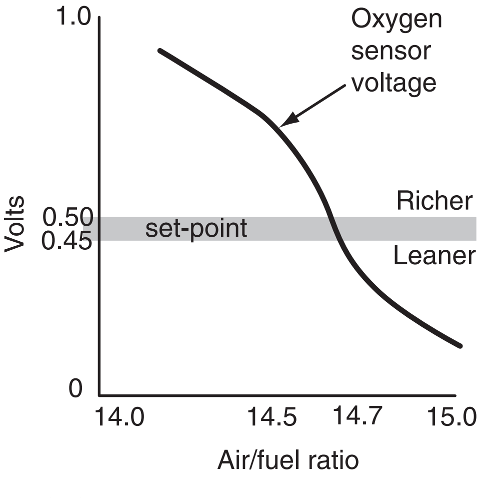


Figure 3–6 Relation of oxygen sensor signal voltage to air/fuel ratio (approximate).

The engine computer has two terminals for the oxygen sensor circuit—one for the oxygen sensor's positive signal and one for the oxygen sensor's negative signal (signal ground). That is, the voltage-sensing circuits within the computer must use two wires to measure the oxygen sensor's voltage, similar to how you would use a voltmeter to do the same thing. Although some oxygen sensors complete both circuits using insulated wiring, resulting in a two-wire oxygen sensor, many applications use the metal of the engine block to complete the signal ground circuit, resulting in a single-wire oxygen sensor.

By the late 1980s, most manufacturers were using heated oxygen sensors on many applications. The operation of the oxygen sensor itself is no different, but a heating element is added to (and placed within) the oxygen sensor to heat it to operating temperature more quickly and to help it maintain proper operating temperature when contacted by cooler exhaust gasses, such as at idle. The addition of a heating element also allows it to be placed further downstream in the exhaust system so that it can sample a more accurate average of the exhaust gas produced by all cylinders. The addition of a heating element results in the addition of two current-carrying wires to the oxygen sensor, one that provides power for the heater when the ignition is switched on and one that is connected to a fixed ground. As a result, what was previously a single-wire oxygen sensor will now have three wires and what was previously a two-wire oxygen sensor will now have four wires. The heater circuit is not part of the computer control system, but on newer applications the engine computer monitors the heater circuit for continuity and proper operation.

Although the zirconium oxygen sensor is by far the most common type, another type that is used on some gasoline engine applications is the titania oxygen sensor. A titania oxygen sensor works more like a coolant-temperature sensor in that it modifies applied reference voltage by changing its resistance internally in response to changes in air/fuel ratios. Instead of a gradual change in resistance as with other resistance-changing sensors, it changes its resistance rapidly from less than 1000 Ω when the air/fuel ratio is rich to more than 20,000 Ω when the air/fuel ratio is lean. The PCM supplies it with a reference voltage, and it sends back a portion of it as the sensor's signal voltage. On most applications, this reference voltage is 1 V, thereby allowing this sensor to operate between 0 and 1 V and in a fashion similar to a zirconium oxygen sensor, although the voltage signal may operate backwards, so that a high voltage may represent a lean air/fuel ratio and a low voltage may represent a rich air/fuel ratio. A few applications have used a 5-V reference for this sensor.

Oxygen sensors are subject to contamination under certain conditions. Contaminating either electrode surface will shield it from oxygen and adversely affect its performance. (The outside electrode is more vulnerable because it is exposed to exhaust gasses.) Prolonged exposure to a rich fuel mixture exhaust can cause it to become carbon fouled. This fouling can sometimes be burned off by operating in a lean condition for 2 or 3 minutes. The oxygen sensor will also be fouled by exposure to:

- lead from leaded gasoline,
- vapors from a silicone-based gasket-sealing compound,
- antifreeze residue of coolant leaking into the combustion chamber,
- engine oil in the exhaust.

Diagnostic & Service Tip

Oxygen Sensors and Mixture. Technicians should remember that, while the oxygen sensor's signal is central to the control of air/fuel mixture, it does not directly sense that mixture. All the oxygen sensor can respond to is the difference in oxygen in the two different gasses (ambient air and exhaust gas). Anything other than combustion that allows a change in the oxygen content of the exhaust will thus make the sensor's signal inaccurate. If there is an air leak into the exhaust, perhaps around the exhaust manifold, the sensor will report a lean mixture and the computer will attempt to correct for it by enriching the mixture—exactly the wrong tactic. If a spark plug fails to deliver the ignition spark, the air in that cylinder's charge will not be consumed but will go into the exhaust. The sensor will again perceive an overly lean condition and the computer will try to enrich the air/fuel mixture. For the computer's sensors, you must remember exactly what each one is measuring before you can know what the possibilities are for corrective measures.

Fouling by these materials will probably require that the oxygen sensor be replaced. Additionally, if the ambient air vent were to become plugged with mud or some other substance such as undercoating, ambient air would be restricted from reaching the zirconium dioxide element. This is also cause for replacement.

Thermistors

A **thermistor** is a resistor made from a semiconductor material. Its electrical resistance changes greatly and predictably as its temperature changes. At –40°F (–40°C), a typical thermistor can have a resistance of 100,000 Ω. At 212°F (100°C), the same thermistor can likely have a resistance between 100 Ω and 200 Ω. Even small changes in temperature can be observed by monitoring a thermistor's resistance. This characteristic makes it an excellent means of measuring the temperature of such things as water (engine coolant) or air.

There are negative temperature coefficient (NTC) and positive temperature coefficient (PTC) thermistors. The resistance of the NTC thermistor goes down as its temperature goes up, while the resistance of the PTC type goes up as its temperature goes up. Most thermistors that are used as temperature sensors in automotive computer systems are the NTC type. A good example is an engine coolant temperature sensor, common to most computerized engine control systems. The coolant temperature sensor consists of an NTC thermistor in the nose of a metal housing (Figure 3–7). The sensor's housing is screwed into the engine (usually in the head or thermostat housing) with its nose extending into the water jacket so that the thermistor element will be the same temperature as that of the coolant. The PCM sends a 5-V reference voltage through a fixed resistance and then to the sensor (Figure 3–8). A small amount of current flows through the thermistor (usually shown as a resistor symbol with an arrow diagonally across it) and returns to ground through the PCM. This is a voltage-divider circuit (current flows through the first resistance and then through the second resistance) and is commonly

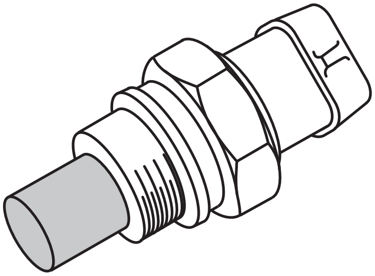


Figure 3–7 Coolant temperature sensor.

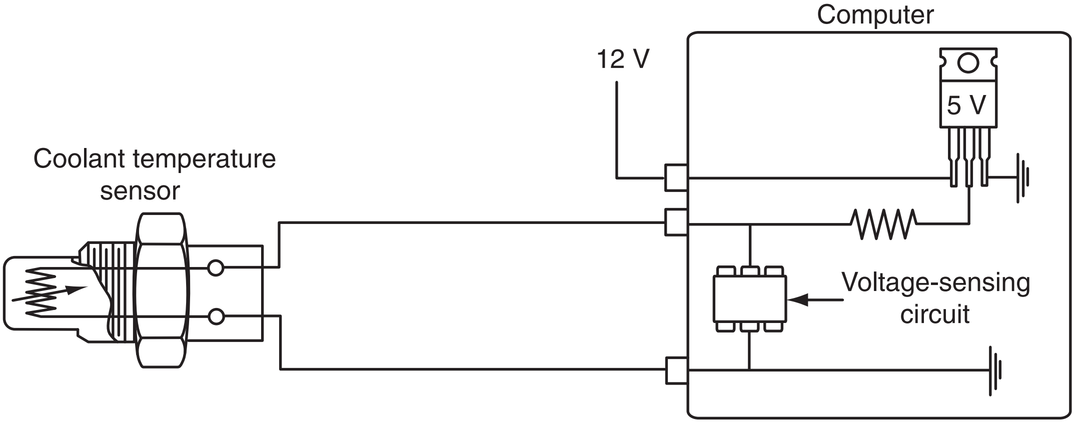


Figure 3–8 Temperature-sensing circuit.

used as a temperature-sensing circuit. Because the resistance of the thermistor changes with temperature, the voltage drop across it changes also. The computer monitors the voltage drop across the thermistor and, using preprogrammed values, converts the voltage drop to a corresponding temperature value.

Many modern systems use a more complex engine coolant temperature sensor called a *range-switching* or *dual range sensor.* As the engine warms up, the thermistor's resistance decreases, causing the voltage drop across the sensor to decrease. At about 110°F to 120°F (Chrysler), the computer lowers the effective resistance within the computer (by adding another resistor in parallel to it). This instantly increases the voltage drop across the sensor by effectively transferring it from the internal resistance. As the engine continues to warm up, the voltage drop across the sensor decreases a second time. This allows the computer to see more voltage change as the engine warms up than the supplied 5-V reference signal would normally allow, thereby increasing the accuracy of the sensor input. This is also used to extend the temperature-sensing range of the engine coolant temperature sensor on those engines that utilize a coolant over-temp protection strategy.

If an open circuit develops in either of these temperature-sensing circuits (either by reason of the sensor or the circuitry itself), the computer sees full reference voltage and interprets this as a signal representing about –40°F. This is due to the fact that without any current flow in the circuit, the fixed resistor within the computer will not drop any voltage.

Potentiometers

A **potentiometer** is another application of a voltage divider circuit. It is formed from a carbon resistance material (or, in higher wattage potentiometers, a wound resistance wire) that has reference voltage supplied to one end and is grounded at the other end. It has a movable center contact (or wiper) that senses the voltage at a physical point along the resistance material (Figure 3–9). At any position of the wiper, there is always some resistance both before and after the point of wiper contact. That

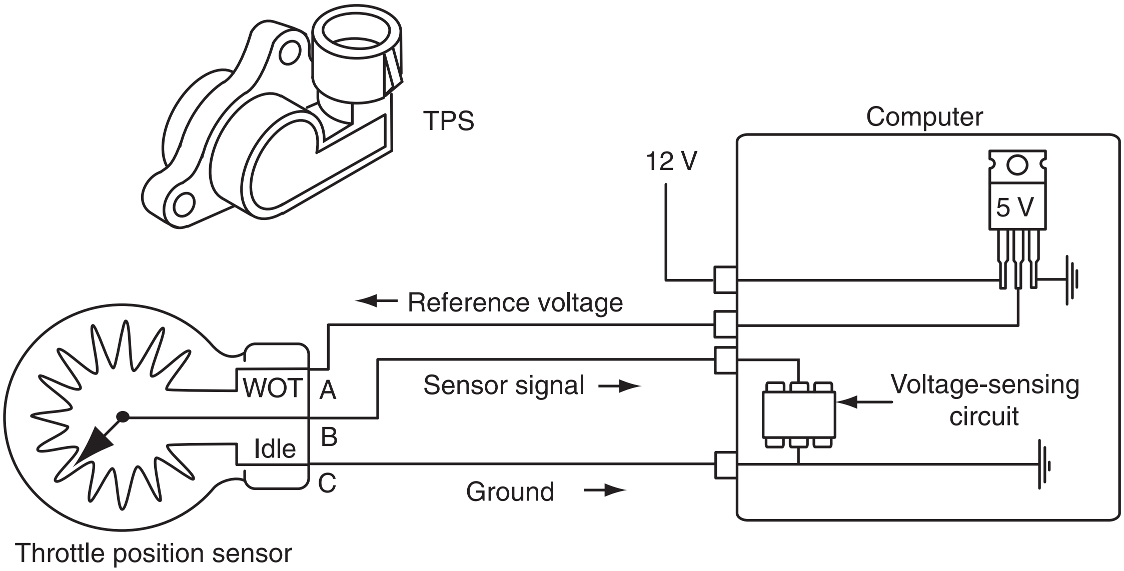


Figure 3–9 Potentiometer as throttle position sensor.

is, some of the reference voltage is dropped before the point of wiper contact and the remainder of the reference voltage is dropped after the point of contact. As the wiper slides along the resistance material, the voltage signal changes. This voltage signal equates to the voltage drop that occurs after the point of wiper contact and is fed to the PCM as the sensor's voltage signal. A potentiometer measures physical position and is used to sense either linear or rotary motion.

For example, when a potentiometer is used as a throttle position sensor, as depicted in Figure 3–9, the potentiometer would typically be mounted on one end of the throttle shaft. As the throttle is opened, the throttle shaft rotates and moves the wiper along the resistance material. The computer sends a 5-V reference voltage to point A. If the wiper is positioned near point A (**wide-open throttle [WOT]** on most applications), there will be a low voltage drop between points A and B (low resistance), and a high voltage drop will exist between points B and C. When the wiper is positioned near point C (idle position on most applications), there is a high voltage drop between points A and B and a low drop between points B and C. The computer monitors the voltage drop between points B and C and interprets a low voltage, 0.5 for example, as idle position. A high voltage, around 4.5, will be interpreted as WOT. Voltages between these values will be interpreted as a proportionate throttle position.

A potentiometer has a higher wear factor than any other type of sensor due to the frequent physical movement of the wiper across the resistance material. As a result, it is quite common for a potentiometer to develop points along the wiper's travel that result in a loss of electrical contact. The term **potentiometer sweep test** refers to the testing of a potentiometer throughout its range of operation to determine if any electrical opens exist. Additionally, if a potentiometer loses its ground, the computer will sense full reference voltage in all positions of the wiper because the voltage-sensing circuits of the computer do not load the potentiometer circuit.

Pressure Sensors

Pressure sensors are commonly used to monitor intake manifold pressure and/or **barometric pressure (BP).** Intake manifold pressure is a direct response to throttle position and engine speed, with throttle position being the most significant factor. The greater the throttle opening, the greater the manifold pressure becomes (lower vacuum). At WOT, manifold pressure is nearly 100 percent of atmospheric pressure, reduced only by the slight energy consumed by friction with the intake channel walls. Intake manifold pressure can therefore be translated as close to engine load; this is a critical factor in determining many engine calibrations. Barometric pressure is the actual ambient pressure of the air at the engine. It also impacts manifold pressure and in most systems is considered when calculating engine calibrations such as air/fuel mixture and ignition timing.

Intake manifold pressure (usually a negative pressure or *vacuum* unless the vehicle is equipped with a turbocharger or supercharger) and/or BP are, on most systems, measured with a silicon diaphragm that acts as a resistor (Figure 3–10). The resistor/diaphragm (about 3 mm wide) separates two chambers. As the pressure on the two sides of the resistor/diaphragm varies, it flexes. The flexing causes the resistance of this semiconductor material to change. The computer applies a reference voltage to one side of the diaphragm. As the current crosses the resistor/diaphragm, the amount of voltage drop that occurs depends on how much the diaphragm is flexed. The signal is passed through a filtering circuit before it is sent to the computer as a DC analog signal. The computer monitors the voltage drop and, by using a look-up chart of stored pressure values, determines from the returned voltage the exact pressure to which the diaphragm is responding.

Two slightly different pressure sensor designs use the **piezoresistive** silicon diaphragm: the absolute pressure and the pressure differential

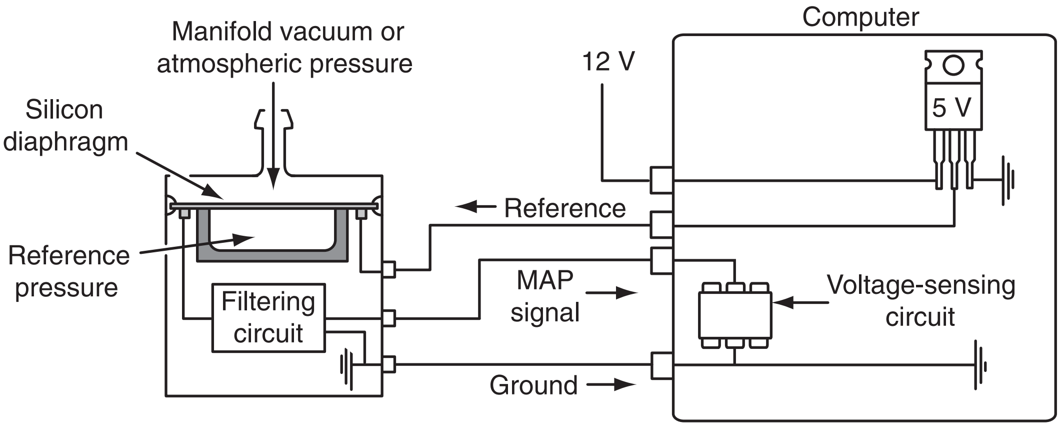


Figure 3–10 Silicon diaphragm pressure sensor.

sensors (Figure 3–11). In one design, the chamber under the diaphragm is sealed and contains a fixed reference pressure. The upper chamber is exposed to either intake manifold pressure or to atmospheric pressure. If the upper chamber is connected to the intake manifold, the sensor functions as a manifold absolute pressure (MAP) sensor. Absolute, as used in the term MAP, refers to a sensor that compares a varying pressure to a fixed pressure. The output signal (return voltage) from this sensor increases as pressure on the variable side of the diaphragm increases (wider throttle opening for engine speed). If the upper chamber is exposed to atmospheric pressure, the sensor functions as a BP sensor. Modern PCMs take an initial reading from the MAP sensor during the initial key-on, engine start sequence that is then used as a BP reference for the next driving trip. The barometric value is also updated using the MAP sensor each time the throttle is opened to the WOT position.

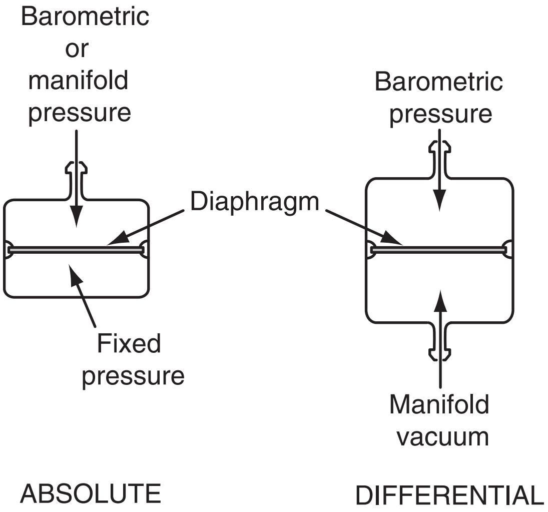


Figure 3–11 Two types of silicon diaphragm pressure sensors.

The differential pressure sensor combines the functions of both the MAP and the BP sensors. Instead of using a fixed pressure, one side of the resistor/diaphragm is exposed to BP and the other side is connected to intake manifold pressure. The output signal is the result of subtracting manifold pressure from BP. The output signal is opposite to the MAP sensor, however, because as manifold pressure decreases (higher vacuum), output voltage increases. The pressure differential sensor had limited use on some early General Motors Computer Command Control systems.

Other types of pressure sensors are discussed in the appropriate chapters.

Speed Density Formula. To know how much fuel to meter into the cylinder, the microprocessor must know how much air, as measured by weight (more accurately, by mass), is in the cylinder. Since the microprocessor has no way to actually weigh the air going into a cylinder, some other method must be used to determine this value. Many systems use a mathematical *calculation* called the **speed density formula.**

$$EP \times EGR \times VE \times MAP/AT = \text{Air density in cylinder}$$

where: EP = engine parameters
EGR = EGR flow
VE = volumetric efficiency
MAP = manifold absolute pressure
AT = air temperature

To make this calculation, all the factors that influence how much air gets into the cylinders must be considered. Throttle position and engine speed affect air intake, and engine temperature (measured as coolant temperature) affects how much heat the air gains as it passes through the induction system and thus affects the air's density in the cylinder. These factors as a group are called *engine parameters.* The microprocessor gets these pieces of information from sensors that are common to all systems.

The amount of air getting into the cylinders is reduced by the amount of exhaust gas that the EGR valve meters into the induction system. With one exception (Ford), early 1980s automotive computers made an assumption as to the rate of EGR flow. This was accomplished by allowing the PCM to take a very passive approach to controlling the EGR system. The PCM then used estimates (based on engine parameters) of the EGR system's flow rate that were stored in the computer's memory. Early 1980s Ford products allowed the PCM to monitor the EGR valve's operation according to the aggressive control strategies programmed into the PCM.

Because the EGR flow rate affects the air/fuel ratio, modern systems use some type of sensor and/or sensor/actuator-based strategy to allow the PCM to monitor the actual flow rate of the EGR system.

Volumetric Efficiency. How much air can be drawn into and exhausted from the cylinders (or how well the engine breathes) is affected by the diameter, length, and shape of the intake manifold runners; the size and number of the intake and exhaust valves; valve lift, timing, and duration; the combustion chamber design; the cylinder size and compression ratio; and the diameter, length, and shape of the exhaust manifold runners. These groups of factors all affect the engine's **volumetric efficiency (VE).** A VE value for any given set of engine parameters is stored in the computer's memory. In principle, VE is the amount of air that gets into the cylinder by the time the intake valve closes, divided by the theoretical amount displaced by the moving piston. Ordinarily, this is less than 100 percent, but VE also varies with engine speed and load. With careful use of valve overlap, VE can sometimes go just above 100 percent for certain engine speeds. Maximum engine torque, of course, occurs just at the highest VE for a given engine. Volumetric efficiency can also be increased through the use of supercharging or turbocharging.

Air Temperature. The air's temperature affects its density and, therefore, how much air enters the cylinders. Most systems use an air temperature sensor to measure the temperature of the intake air. Some early systems used estimates of air temperature that were based on a fairly predictable relationship between coolant temperature and air temperature, the parameters of which were stored in memory. In modern systems, intake air temperature is considered a critical input on those systems that use the speed density formula.

You also know that BP pushes air past the throttle plate(s) and manifold pressure pushes that air past the intake valve into the cylinder. The last known values that must be determined in order to know how much air the engine will inhale during any given set of operating conditions are BP and manifold pressure. The MAP sensor, as you will see in later chapters, almost always provides both pressure values. A MAP sensor identifies those systems that use the speed density formula.

It should also be noted that some older European, Asian, and U.S. vehicles that used the speed density formula used a vane air flow (VAF) meter instead of a MAP sensor. However, these systems did also use a full-time BP sensor as

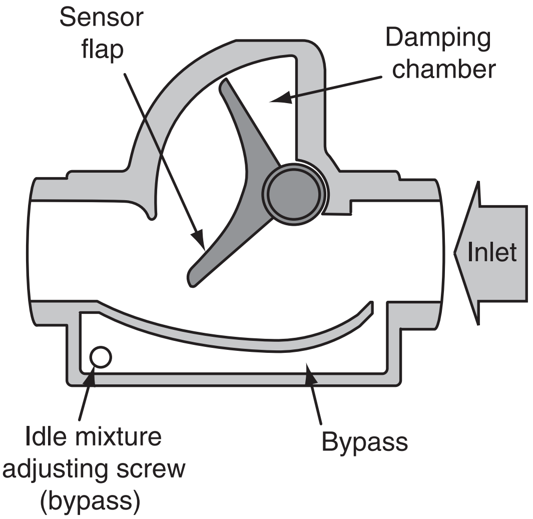


Figure 3–12 Vane air flow (VAF) sensor.

well. The VAF meter was mounted in the intake air stream and used a potentiometer to monitor a spring-loaded door that opened according to the volume of intake air that the engine was drawing through it (Figure 3–12). It also contained an NTC thermistor located just ahead of the door to monitor intake air temperature (sometimes known as a vane air temperature (VAT) sensor (Figure 3–13). A VAF meter, although no longer used, also identifies the use of the speed density formula.

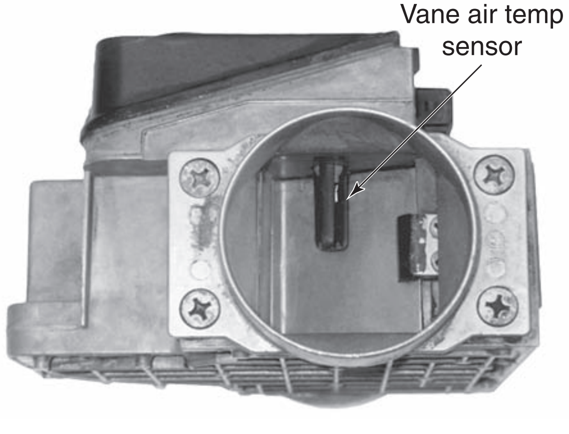


Figure 3–13 Vane air flow (VAF) meter with vane air temperature (VAT) sensor.

Measuring Air Mass

Port fuel injection or multipoint injection has become the predominant fuel-metering system. Although a multipoint fuel injection system offers several distinct advantages over other types of fuel-metering systems, it has one shortcoming. A multipoint injection system provides less opportunity (in time duration) for the fuel to vaporize than does a system where the fuel is introduced earlier in the intake channels, into the center of the intake manifold, and only the fuel that vaporizes before combustion occurs is burned. In the past, this problem was probably most apparent as a lean stumble when accelerating from idle and was the result of the high manifold pressure that comes from the sudden increase in throttle opening. With the throttle open, atmospheric pressure forces air into the manifold faster than the engine can use it. The turbulence produced during the intake and compression strokes (and the increased oxygen density on turbocharged applications) help to atomize the fuel and hasten its vaporization. This condition is only completely overcome, however, by spraying in additional fuel to compensate for the failure of the heavier hydrocarbon molecules to vaporize. The capabilities of a digital computer allow for the calculation of just the right amount of fuel to avoid a lean stumble without sacrificing economy or increasing emissions.

For an engine at a given operating temperature and an identified set of atmospheric conditions (air temperature, pressure, and humidity), there is one precise amount of fuel that should be injected into the intake port for each manifold pressure value within the operating range. This amount will provide an evaporated 14.7 to 1 air/fuel ratio in the combustion chamber with the lowest possible leftover unvaporized, unburned hydrocarbons.

Mass Air Flow (MAF) Sensor. The MAP sensor used with the speed density formula has been reasonably effective in enabling the microprocessor to accurately determine the mass of the air that goes into the cylinder. Keep in mind that the microprocessor quantifies both the air and the fuel by weight when calculating

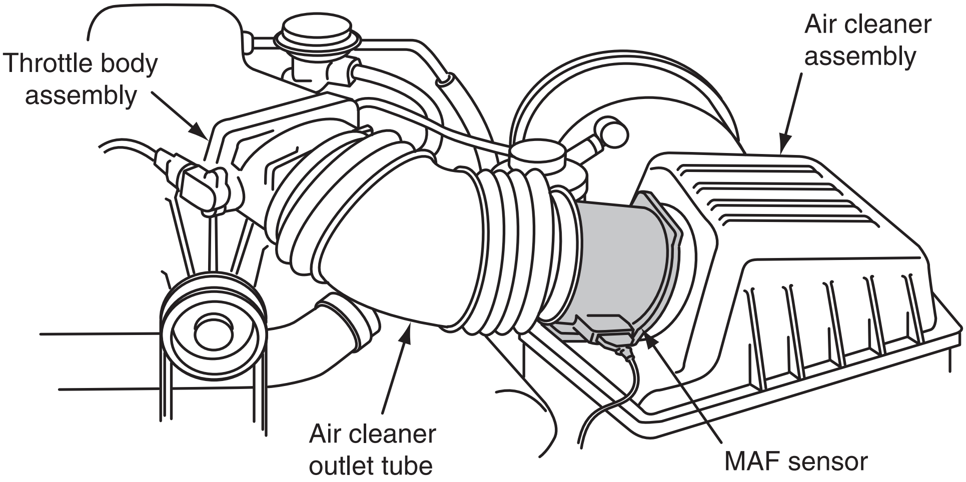


Figure 3–14 Mass air flow (MAF) sensor location.

air/fuel ratios. The VAF meter, as used on older vehicles, was also fairly effective in providing the microprocessor with the needed information to calculate the air's mass. Each of these two methods has, however, been unable to measure one factor that affects the air's mass—humidity.

The MAF sensor, introduced in the mid-1980s, provides information to the microprocessor that accounts for the air flow's rate and density, including those factors that affect the air's density: air temperature, BP, and the air's humidity.

A MAF sensor can actually determine the air flow mass by *measuring* the quantity of air molecules that enter the engine (as opposed to a speed density application, in which the computer *calculates* how much air enters the engine). It does this by measuring the air's ability to cool. Air that flows over an object that is at a higher temperature than the air carries heat away from the object. The amount of heat carried away depends on several factors: the difference in temperature between the air and the object, the object's ability to conduct heat, the object's surface area, the air's mass, and the air's flow rate.

The MAF sensor, sometimes referred to as a *hot-wire sensor,* is placed in the duct that connects the air cleaner to the throttle body so that all of the air entering the induction system must pass through it (Figure 3–14). Within the MAF assembly, intake air flows across both a thermistor and a *hot wire* that is kept heated to a predetermined temperature. A MAF sensor essentially measures how much current it takes to keep the hot wire at its assigned temperature. This assigned temperature is not an absolute temperature, but rather a temperature that is a specific number of degrees hotter than the intake air as measured by the thermistor. Restated, the temperature of the hot wire is indexed to the temperature of the intake air. Because of this, a cold air molecule on a December day will not fool the sensor into believing that a greater volume of air molecules flowed through the sensor as opposed to a warm air molecule on a hot day in July or August.

In one design, the thermistor and heated wire are located in a smaller air sample tube (Figure 3–15). The thermistor measures the incoming air temperature. The heated wire is maintained at a predetermined temperature above the intake air's temperature by a small electronic module mounted on the outside of the sensor's body. The volume of air flowing through the air sample tube is proportional to the total volume of air flowing through the totality of the sensor.

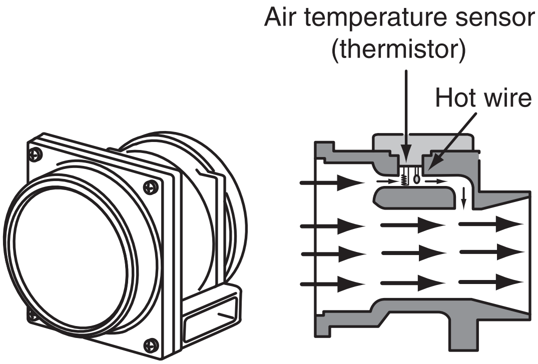


Figure 3–15 Components of a hot wire–type mass air flow (MAF) sensor.

In this design, the heated wire is actually one of several resistors in a circuit. Figure 3–16 represents a simplified MAF balanced bridge circuit. The module supplies battery voltage to the balanced bridge. Resistors R1 and R3 form a series circuit in parallel to resistors R2 and R4. The voltage at the junction between R1 and R3 is equal to the voltage drop across R3. Because the values of R1 and R3 are fixed, the voltage at this junction is constant; it will vary, but only as battery voltage varies. Resistors R1 and R2 have equal values. With no air flow across R4, its resistance is equal to R3, and the voltage at the junction between R2 and R4 is equal to the voltage at the R1/R3 junction.

As air flow across R4 increases, its temperature drops, and because it is a PTC resistor, its resistance goes down with its temperature. As the air's mass increases, R4's resistance goes down even more. As the resistance of R4 goes down, a smaller portion of the voltage applied to the circuit formed by R2/R4 is dropped across R4. Therefore, a larger portion of the voltage is dropped across R2. So, as the resistance of R4 goes down, the voltage at the R2/R4 junction goes down. The computer reads the voltage difference between the R1/R3 junction and the R2/R4 junction as the MAF sensor value. By looking at a table in the computer's memory, the microprocessor converts the voltage value to a MAF rate.

A MAF sensor does not actually measure BP or humidity. But, because it is an air molecule counter, it will be accurate for the total mass of

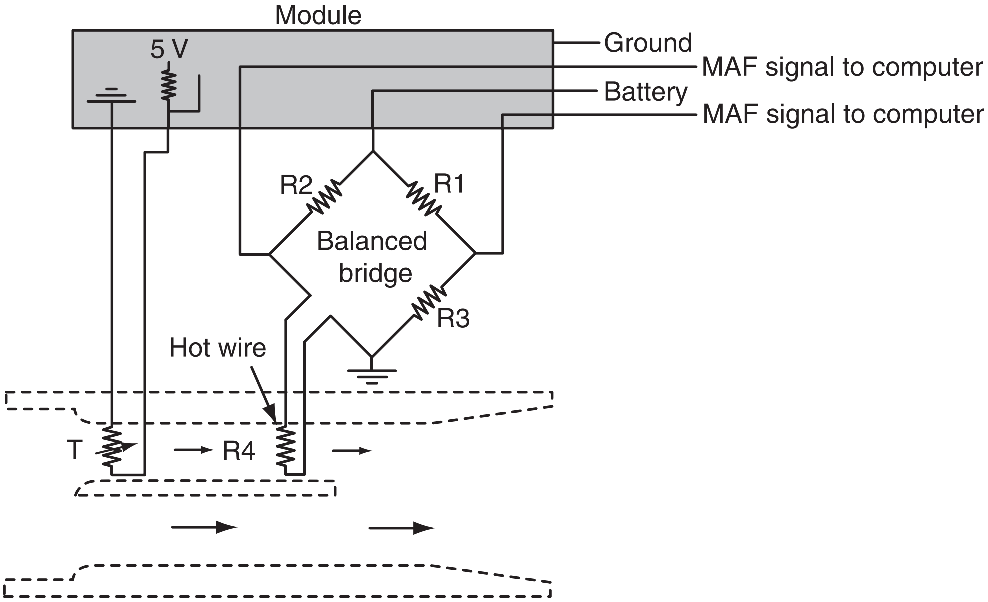


Figure 3–16 MAF sensor circuit.

the intake air regardless of what might affect the air's density, including BP and humidity.

Another advantage of a MAF sensor is that a MAF sensor tends to maintain a higher level of accuracy as the engine wears than the MAP sensor in a speed density system. This is because an engine tends to develop less manifold vacuum with wear and age. When compared to BP as a reference, a MAP sensor on a speed density application tends to interpret this lower level of manifold vacuum as increased engine load, thereby causing the PCM to mistakenly add too much fuel to the incoming air. But a MAF sensor retains its accuracy as the engine wears, continuing to measure accurately the mass of air that is being drawn into the engine, thus allowing the PCM to deliver the correct amount of fuel in spite of the engine wear.

Magnetic Sensors

Magnetic sensors, also sometimes known as permanent magnet sensors or variable reluctance sensors, consist of a coil of wire wrapped around a permanent magnet (Figure 3–17). Magnetic sensors are voltage-generating devices. A permanent magnet sensor operates on the principle that magnetic fields are able to cause electron flow as they expand or collapse across a coil of wire. A series of iron teeth and notches are passed near the magnet. As an iron tooth approaches the magnet, the magnet's magnetic field strength is increased and a voltage potential is generated within the coil of wire that is wrapped around the magnet. Then, as the iron tooth pulls away from the magnet, the magnet's magnetic field strength is decreased and a voltage potential of the opposite polarity is generated within the coil of wire. As a result, a magnetic sensor produces an AC voltage. Generally, the computer is not so concerned with how much voltage is produced (as long as enough voltage is produced to make the signal recognizable to the computer); instead, it is more concerned with the timing of the AC voltage pulse and/or the frequency of the voltage pulses. A magnetic sensor is a two-wire sensor, although some applications will also add a wire for a grounded shield, visible as a third wire at the first electrical connector near the sensor.

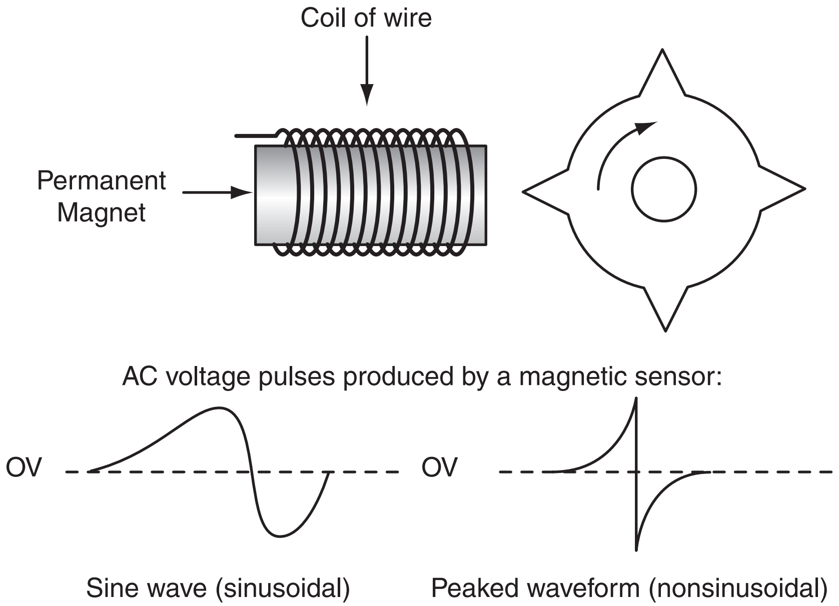

Coil of wire
Permanent Magnet
AC voltage pulses produced by a magnetic sensor:
OV
OV
Sine wave (sinusoidal)
Peaked waveform (nonsinusoidal)

Figure 3–17 Permanent magnet sensor.

Testing of a magnetic sensor consists of using an ohmmeter to measure the resistance of the sensor's coil of wire and comparing the result to the sensor's specification. Then a voltmeter should be used (on an AC voltage scale) to test the sensor's ability to produce a voltage signal while the sensor is operating. Also, if the sensor has a metallic body, an ohmmeter should be used to verify that the sensor's coil of wire is not grounded (shorted) to the sensor's frame (this step is not important with plastic-bodied magnetic sensors).

Permanent magnet sensors are commonly used as ignition pickups and vehicle speed sensors, and are used in many other applications as well.

Hall Effect Switches

A **Hall effect switch** is frequently used to sense engine speed and crankshaft position. It provides a signal each time a piston reaches top dead center; this signal serves as the primary input on which ignition timing is calculated. Because of the frequency with which this signal occurs and the critical need for accuracy, the Hall effect switch is a popular choice because it and its related circuitry provide a digital signal. On some applications, a separate Hall effect switch is used to monitor camshaft position as well.

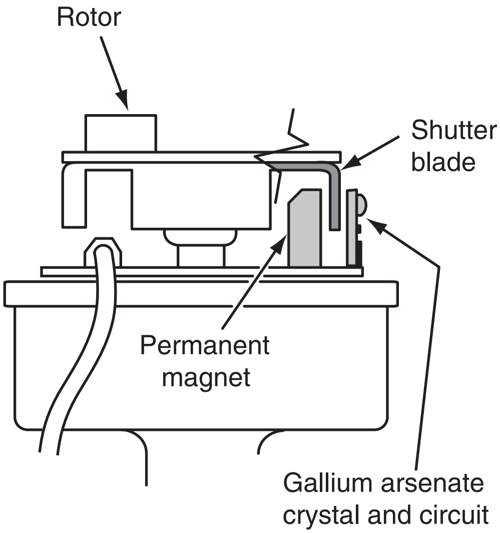


Figure 3–18 Hall effect switch.

A Hall effect switch consists of a permanent magnet, a **gallium arsenate crystal** with its related circuitry, and a shutter wheel (Figure 3–18). The permanent magnet is mounted so that there is a small space between it and the gallium arsenate crystal. The shutter wheel, rotated by a shaft, alternately passes its vanes through the narrow space between the magnet and the crystal (Figure 3–19).

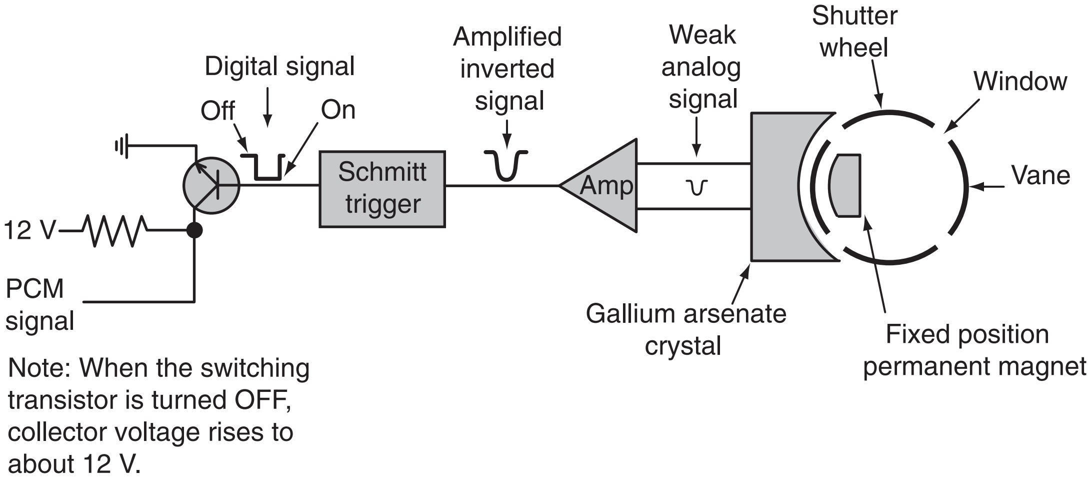

Digital signal
Off
On
Amplified inverted signal
Weak analog signal
Shutter wheel
Window
Vane
Schmitt trigger
Amp
12 V
PCM signal
Gallium arsenate crystal
Fixed position permanent magnet
Note: When the switching transistor is turned OFF, collector voltage rises to about 12 V.

Figure 3–19 Hall effect switch circuit.

When a vane is between the magnet and the crystal, the vane intercepts the magnetic field and thus shields the crystal from it. When the vane moves out, the gallium arsenate crystal is invaded by the magnetic field. A steady current is passed through the crystal from end to end. When the magnetic lines of force from the permanent magnet invade the crystal, the current flow across the crystal is distorted. This will result in a weak voltage potential being produced at the crystal's top and bottom surfaces—negative at one surface and positive at the other. As the shutter wheel turns, the crystal provides a weak high/low-voltage signal.

This signal is usually modified before it is sent to the computer. For example, as shown in Figure 3–19, the signal is sent to an amplifier, which strengthens and inverts it. The inverted signal (high when the signal coming from the Hall effect switch is low) goes to a **Schmitt trigger** device, which converts the analog signal to a digital signal. The digital signal is fed to the base of a switching transistor. The transistor is switched on and off in response to the signals generated by the Hall effect switch assembly.

When the transistor is switched on, it completes another circuit to ground and allows current to flow. The other circuit can come from the ignition switch or from the PCM, as shown in Figure 3–19. In either case it has a resistor between its voltage source and the transistor. A voltage-sensing circuit in the computer connects to the circuit between the resistor and the transistor. When the transistor is on and the circuit is complete to ground, a voltage drop occurs across the resistor. The voltage signal to the voltage-sensing circuit is less than 1 V. When the transistor is switched off, there is no drop across the resistor, and the voltage signal to the voltage-sensing circuit is near 12 volts. The PCM will monitor the voltage level and will determine by the frequency at which it rises and falls what the engine speed is. Each time it rises, the computer knows that a piston is approaching top dead center.

While many Hall effect switches use the concept just described, involving passing iron vanes and windows between a Hall effect crystal and a stationary permanent magnet, there are two other types of Hall effect sensors.

The first variation is to simply move a permanent magnet past a stationary Hall effect sensor (Figure 3–20). Usually the Hall effect sensor is mounted through the engine's timing gear cover, and the permanent magnet is mounted to the

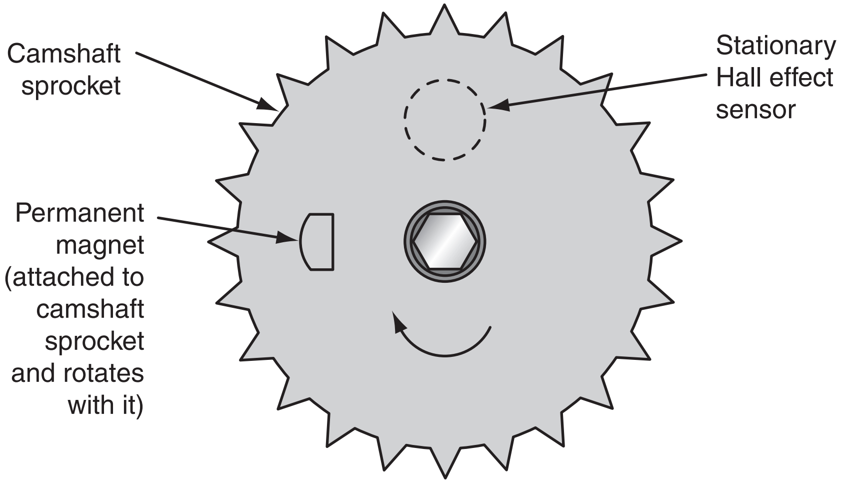

Camshaft sprocket
Stationary Hall effect sensor
Permanent magnet (attached to camshaft sprocket and rotates with it)

Figure 3–20 Hall effect sensor with rotating magnet.

camshaft sprocket. As the magnet rotates past the Hall effect sensor, a signal is produced that is similar to that of a camshaft sensor, which rotates a vane cup between a Hall effect switch and a stationary permanent magnet.

The other variation is to install both a permanent magnet and a Hall effect crystal in a plastic body, similar in appearance to many magnetic sensors used today, except for the number of wires connected to the sensor (Figure 3–21). The magnet is placed at the forward end of the sensor's body, and the Hall effect crystal is placed toward the rear. Iron vanes and windows that are designed into a flywheel or camshaft sprocket are rotated past the forward end of the sensor where the magnet is located. When iron is placed near the magnet, its field strength increases enough to envelop the Hall effect crystal placed in the body behind it. As the vanes and windows are rotated past the sensor, this action causes the Hall effect crystal to generate a waveform signal that is similar to other Hall effect sensors.

Hall effect sensors are also used as vehicle speed sensors, as well as for ignition system pickups. Ultimately, regardless of which style of Hall effect sensor is used, the sensor will have three wires exiting the body (unlike simple magnetic sensors, which only have two). As an electronic component, two of the wires will supply the voltage and ground needed for the sensor to "come alive." The third wire is the signal wire. When testing, check the power and ground wires. The applied

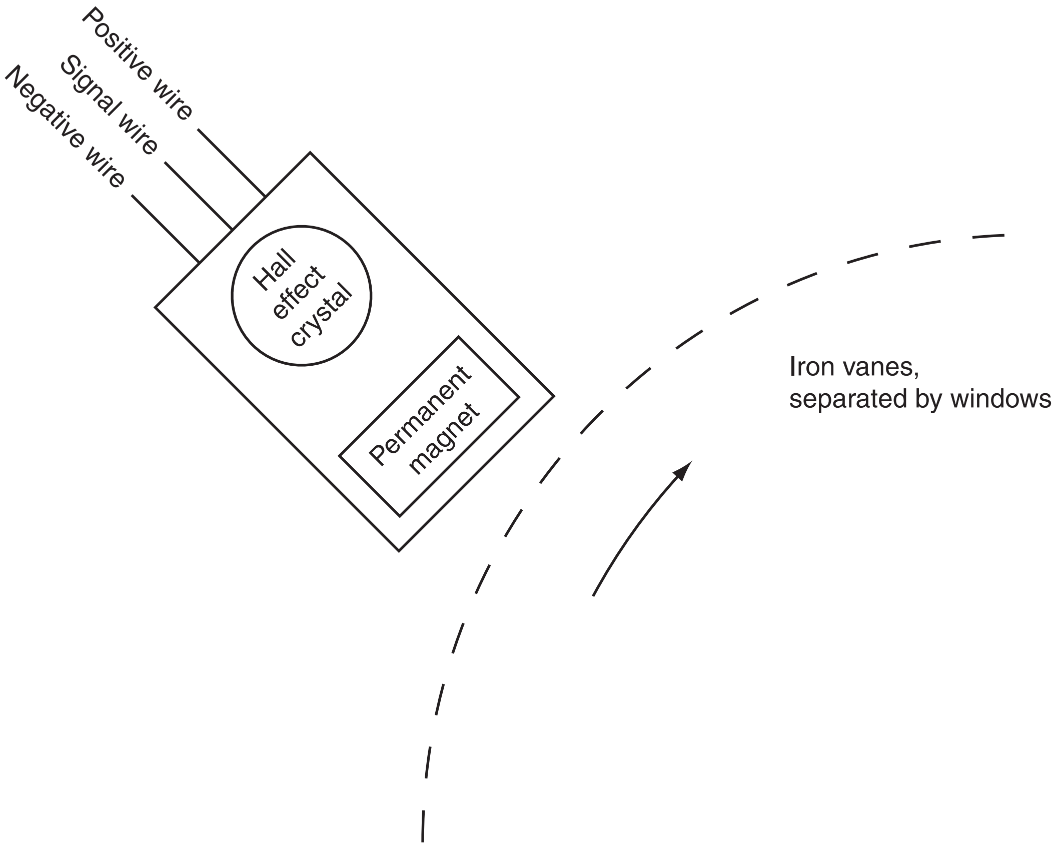


Figure 3–21 Hall effect sensor that contains a permanent magnet.

voltage will be as high as the charging system voltage on some applications. On other applications, such as Chrysler vehicles, as little as 8 V is used to power this sensor (this voltage originates at the PCM). Once the power and ground have been verified, check the signal wire for digital DC voltage pulses with the sensor operating (engine cranking). If an oscilloscope is not available, average DC voltage can be measured and should average between about 30 percent and 70 percent of the applied voltage, indicating that voltage pulses between zero volts and the applied voltage are likely occurring. Some Hall effect sensors are dual sensors, having a total of four wires—one for shared power, one for a shared ground, and two individual signal wires. Both signal wires should be checked for voltage pulses.

Optical Sensors

Several manufacturers use optical sensors to sense crankshaft position and RPM, either in the form of an optical distributor or in the form of an optical crankshaft or camshaft sensor. An optical sensor places a **light-emitting diode (LED)** opposite a photocell with a rotating slotted wheel between them (Figure 3–22). Generally, the LED transmits infrared light and the photocell is sensitive to infrared light, so visible light wavelengths do not affect the sensor. As the slotted wheel

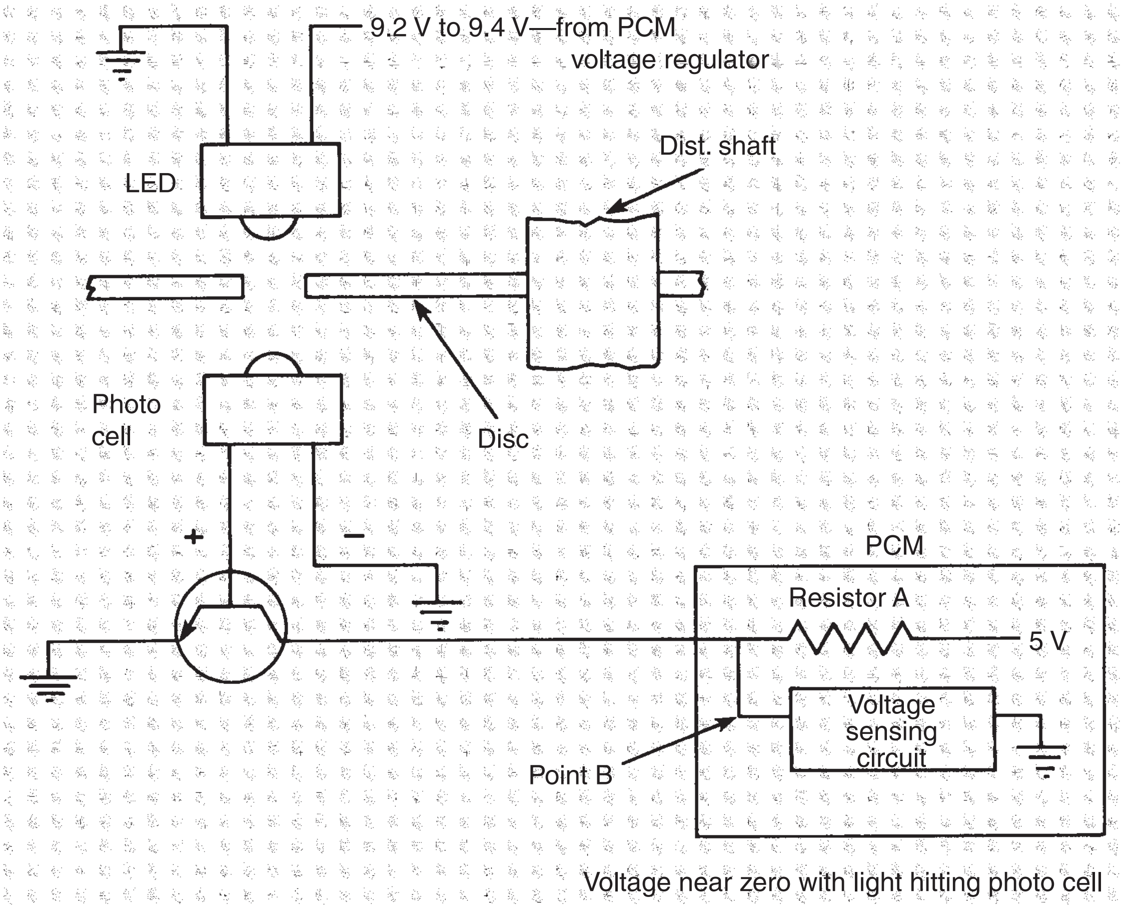

9.2 V to 9.4 V—from PCM voltage regulator
Dist. shaft
LED
Photo cell
Disc
+
–
PCM
Resistor A
5 V
Voltage sensing circuit
Point B
Voltage near zero with light hitting photo cell

Figure 3–22 Optical sensor in a distributor.

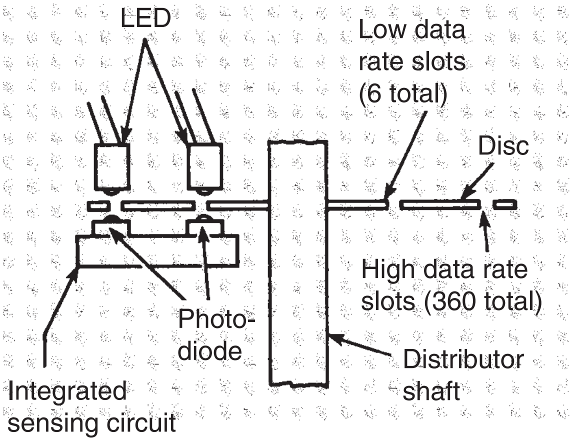

LED
Low data rate slots (6 total)
Disc
High data rate slots (360 total)
Photo-diode
Distributor shaft
Integrated sensing circuit

Figure 3–23 Optical distributor pickup with dual sensors.

rotates, light pulses applied to the photocell cause the photocell to produce enough voltage to forward bias a transistor that then grounds out a monitored circuit, thus producing DC digital voltage pulses. On distributor applications that use an optical sensor, the sensor body actually contains two LED and photocell assemblies (Figure 3–23), one monitoring a low-resolution signal with one slot per engine cylinder and the other monitoring a high-resolution signal with one slot per degree of distributor rotation, or 360 slots (these are actually very small, laser-cut slits). Optical distributors are used by, and they are used by others as well. One Mitsubishi application uses a dual optical sensor as a camshaft sensor on a distributorless (multiple coil) application. Interestingly, Mitsubishi makes many of the optical sensors for General Motors, Nissan, and the Chrysler Mitsubishi engines.

Like a Hall effect sensor, an optical sensor requires a voltage and a ground just to “come alive.” The third and fourth wires are individual signal wires for each of the dual optical sensors. When testing, verify proper applied voltage and ground first, then test the signal wires with an oscilloscope or digital volt/ohm meter (DVOM) while operating the sensor (cranking the engine). Again, as with Hall effect sensors, average voltage should be between about 30 percent and 70 percent of the applied voltage.

Detonation Sensors

To optimize performance and fuel economy, ignition timing must be adjusted so that the maximum pressure from combustion will be achieved between 10 degrees and 20 degrees after top dead center (ATDC) during the power stroke. Therefore, because it takes about 3 milliseconds after the spark plug fires to achieve maximum combustion pressure, the spark plug must be fired early enough so that maximum combustion pressure will be achieved at the correct time. If the crankshaft is rotating at 1800 RPM, then it also stands to reason that it is rotating at a speed of 30 rotations per second (1800 RPM divided by 60 seconds). This equates to 10,800 degrees of rotation per second (30 times 360 degrees) or 10.8 degrees of rotation per millisecond (10,800 divided by 1000 milliseconds). Since it takes 3 milliseconds to reach maximum combustion pressure, at this engine speed the spark plug must fire 32.4 degrees ahead of when peak combustion pressure is desired. Therefore, in order to achieve maximum pressure by 10 degrees after top dead center (TDC), the spark plug must fire at 22.4 degrees before top dead center (BTDC). Therefore, engine speed is one of the factors that influences spark timing. Other factors, including engine load, are used by the PCM to determine the ideal spark timing.

If the spark plug fires later than the ideal timing, the maximum combustion pressure will be produced in the cylinder too late, as the piston is already approaching bottom dead center (BDC) and less useful work will be done for the amount of fuel burned. If the spark plug fires too early, detonation (also known as *spark knock*) will occur. Due to variations in fuel quality, cylinder cooling efficiency, machining tolerances, and their effect on compression ratios, a preprogrammed spark advance schedule can result in spark knock under certain driving conditions. In order to provide an aggressive spark advance program and still avoid spark knock, many systems use a detonation sensor, often referred to as a *knock sensor.* It alerts the computer when

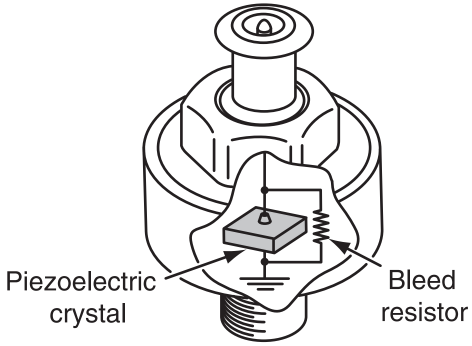


Figure 3–24 Knock sensor.

spark knock occurs so that the timing can be retarded slightly.

The knock sensor (Figure 3–24) is typically mounted in the side of the engine block or in the intake manifold. This location allows it to be subjected to the high-frequency vibration caused by spark knock. Most knock sensors contain a **piezoelectric** crystal. Piezoelectric refers to a characteristic of certain materials that causes them to produce an electrical signal in response to physical stress, or they experience stress in response to an electrical signal. The most commonly used piezoelectric material produces an oscillating AC voltage signal of about 0.3 V or more in response to pressure or vibration. The oscillations occur at the same frequency as the spark knock (5000 to 6000 **Hertz [Hz],** or cycles per second). Spark knock is essentially the ringing of the engine block when struck by the explosion caused by detonation. Although most vibrations within the engine and many elsewhere in the vehicle cause the knock sensor to produce a signal, the computer only responds to signals of the correct frequency.

When testing a knock sensor, tap on the sensor lightly with a metallic object while you measure the resulting output on an oscilloscope or a DVOM set to an AC voltage scale.

Switches

Most systems have several simple switches that are used to sense and communicate information to the computer. The information includes whether the transmission is in gear, the air conditioning is on, the brakes are applied, and so on. With an electronic 4-speed, automatic transmission, two switches may be used, as follows:

- both switches open = 1st gear,
- switch #1 open and switch #2 closed = 2nd gear,
- switch #1 closed and switch #2 open = 3rd gear,
- both switches closed = 4th gear.

Two types of circuits are used by a computer to sense switch inputs. In the most common, the switch completes the path to ground when closed and therefore pulls the applied reference voltage low. Because closing the switch pulls the voltage low, this is known as a *pull-down* circuit (Figure 3–25).

In the other type, a switch applies voltage to a computer-monitored circuit. Because closing the switch pulls voltage high, this is known as a *pull-up circuit* (Figure 3–26).

E-Cells

Some systems use an **E-cell** to indicate to the computer when a specified amount of engine operation has occurred. The E-cell actually measures a specific amount of ignition on-time, which equates to an estimated number of vehicle miles. Its purpose is to alert the computer when the predetermined mileage has occurred so that the computer can adjust specific calibrations to compensate for predictable engine wear.

The E-cell contains a silver cathode and a gold anode. Ignition voltage is applied to the E-cell through a resistor. The passage of current through the cell controls a signal to the computer. As current passes through the cell, a chemical reaction takes place; the silver on the cathode is attracted to the gold anode. After a certain amount of on-time, the silver cathode is completely depleted and the circuit opens. How long this takes is controlled by the amount of current allowed to flow through the E-cell (controlled by how much resistance is in the circuit).

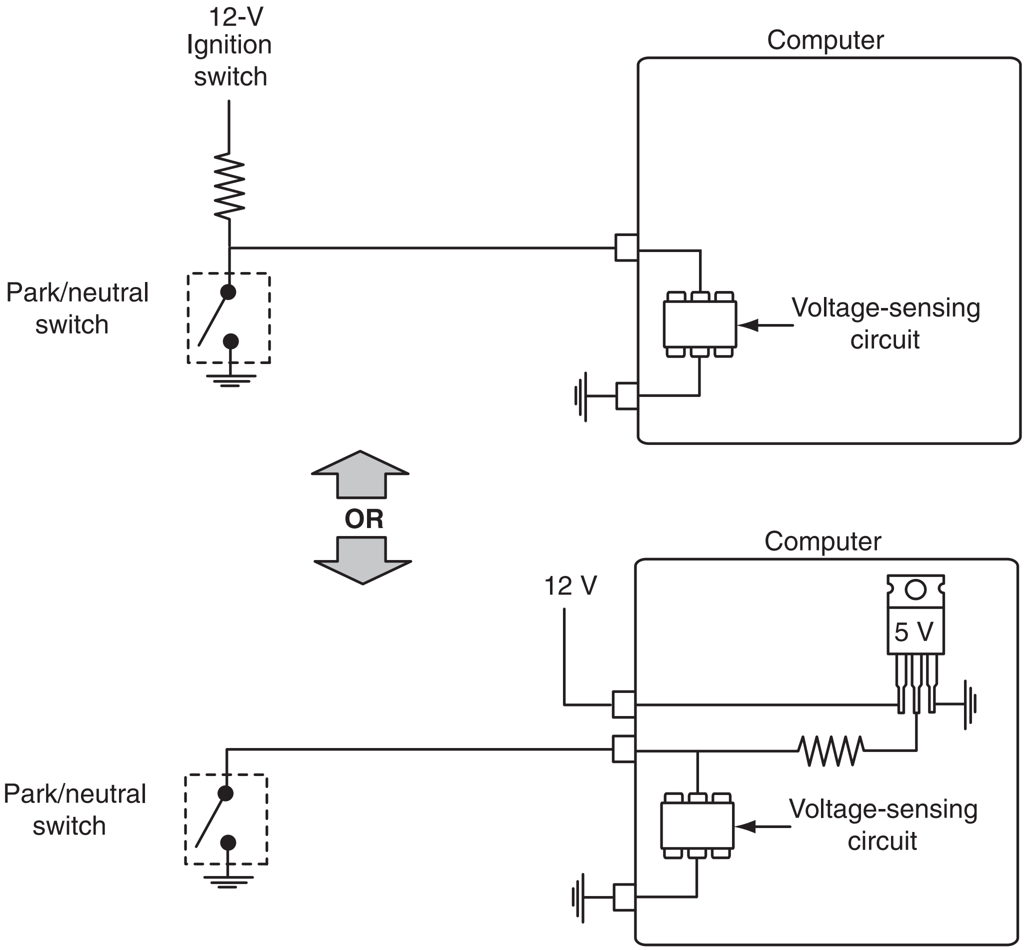


Figure 3–25 Pull-down circuit.

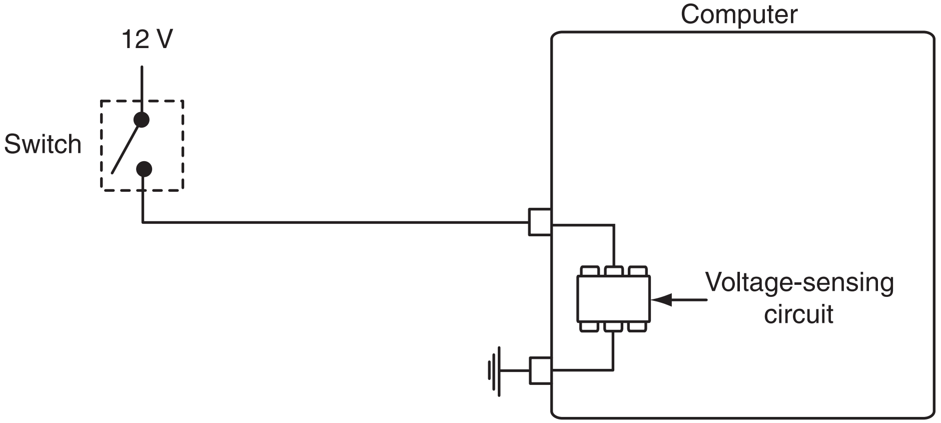


Figure 3–26 Pull-up circuit.

As a rule, E-cells do not need to be serviced, even if they open early or late.

ACTUATORS

Solenoids

The most common actuator is a valve powered by a solenoid. A solenoid-operated valve is designed to control flow and may control liquid fuel (fuel injector), fuel vapors (canister purge solenoid), air (idle air control solenoid), vacuum (vacuum solenoid that controls a vacuum signal to a vacuum-operated component such as an EGR valve), and exhaust gasses (EGR solenoid that controls exhaust gas flow directly without the use of vacuum). Such valves may also be used to control other liquids such as brake fluid (antilock brake solenoid), and even oil or water.

A solenoid-operated valve consists of a coil of wire around a spring-loaded movable iron core (Figure 3–27). When the output driver (transistor) in the computer grounds the solenoid's circuit, the coil is energized. The resulting electromagnetic field developed by the current passing through the coil windings pulls the iron core so as to occupy the entire length of the coil. The movement of the iron core moves the valve attached to the end.

A solenoid-operated valve may be spring-loaded either normally open (N/O) or normally closed (N/C). If it is spring-loaded N/O, then the valve is open and allows flow through it when it is de-energized and will block the flow when it is energized. If it is spring-loaded N/C, then the valve is closed and blocks flow through it when it is de-energized and will allow flow when it is energized. Whether the solenoid is designed N/C or N/O is determined many times by safety considerations—that is, consideration is given to the necessary default in the event that the controlling computer becomes incapable of energizing the solenoid.

Duty-Cycled and Pulse-Width Solenoids. In some cases, the switching circuit that drives the solenoid turns on and off rapidly. If the solenoid circuit is turned on and off (cycled) ten times per second, then the solenoid is duty-cycled. To complete a cycle, it must go from off to on, to off again. If it is turned on for 20 percent of each tenth of a second and off for 80 percent, it is said to be operating on a 20-percent **duty cycle.** In most cases where a solenoid is duty-cycled, the computer has the ability to change the duty cycle to achieve a desired result. The best example of this is the mixture

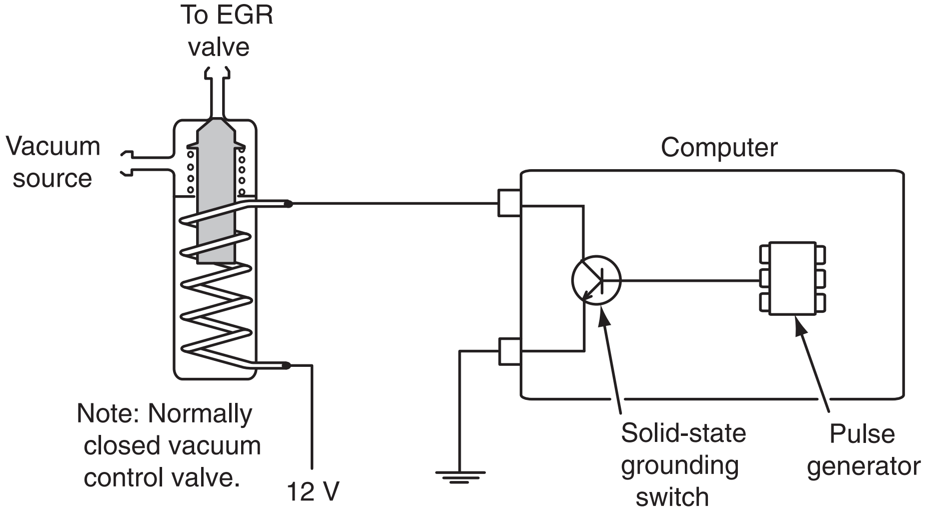

To EGR valve
Vacuum source
Computer
Note: Normally closed vacuum control valve.
12 V
Solid-state grounding switch
Pulse generator

Figure 3–27 Typical solenoid-controlled vacuum valve.

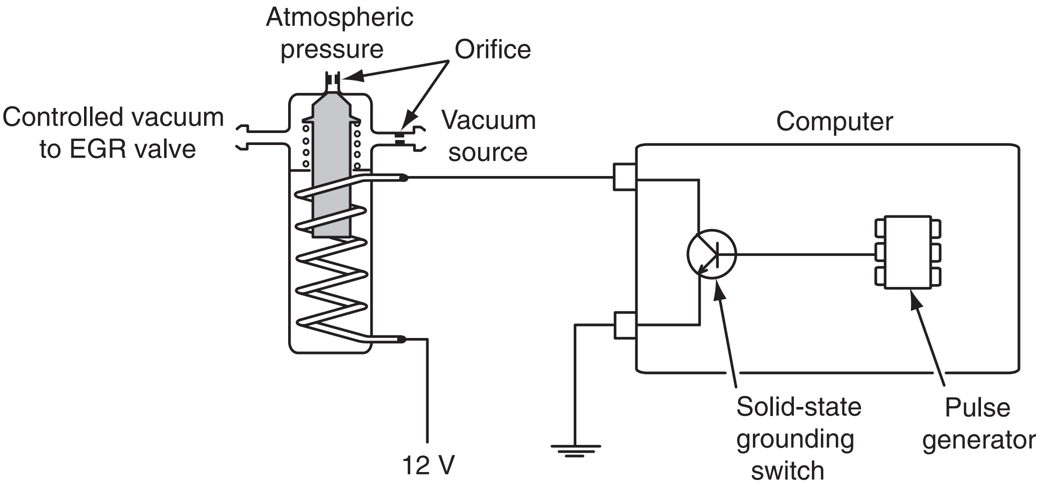


Figure 3–28 Typical pulse-width controlled vacuum valve.

control device on many computer-controlled carburetors, where the duty cycle will change frequently to control the air/fuel mixture.

If a solenoid is turned on and off rapidly but there is no set number of cycles per second at which it is cycled, the on-time is referred to as its *pulse width.* For example, assume that the computer has decided that the EGR valve should be open but that it should be open to only 60 percent of its capacity. The computer can energize a solenoid valve such as the one in Figure 3–27 to allow vacuum to the EGR valve. Figure 3–28 shows a solenoid that, when energized, opens a port that allows atmospheric pressure to bleed into the EGR vacuum line. To control or modulate the amount of vacuum to the EGR valve, the computer issues pulse-width commands to the solenoid. Because the computer wants the EGR valve open to 60 percent of its capacity, it selects pulse widths from a look-up chart to appropriately weaken the vacuum signal to the EGR valve.

Relays

A relay is a remote-control switch that allows a light-duty switch such as an ignition switch, a blower motor switch, a starter switch, or even a driver (transistor) within a computer to control a device that draws a relatively heavy current load. A common example in automotive computer application is a fuel pump relay (Figure 3–29). When the computer wants the fuel pump on, it turns on its driver. The driver applies a ground to the relay coil, which develops a magnetic field in the core. The magnetic field pulls the armature down and closes the N/O contacts. The contacts complete the circuit from the battery to the fuel pump. Because of safety concerns, the fuel pump relay, at least on some systems, is one of the few instances in which the computer supplies a positive voltage, instead of a ground, to energize a load component.

A relay may be spring-loaded N/O or N/C. If it is spring-loaded N/O, then the switch is open and does not allow current flow across the contacts when de-energized and will close and allow current flow when it is energized. If it is spring-loaded N/C, then the switch is closed and allows current flow across the contacts when de-energized and will open the circuit and prohibit current flow when it is energized. Many relays (typical of Bosch relays) have both N/O and N/C contacts. (In a Bosch relay, terminals 85 and 86 are the positive and negative ends of the electromagnetic coil. Terminal 30 is N/O to terminal 87 and N/C to terminal 87a.)

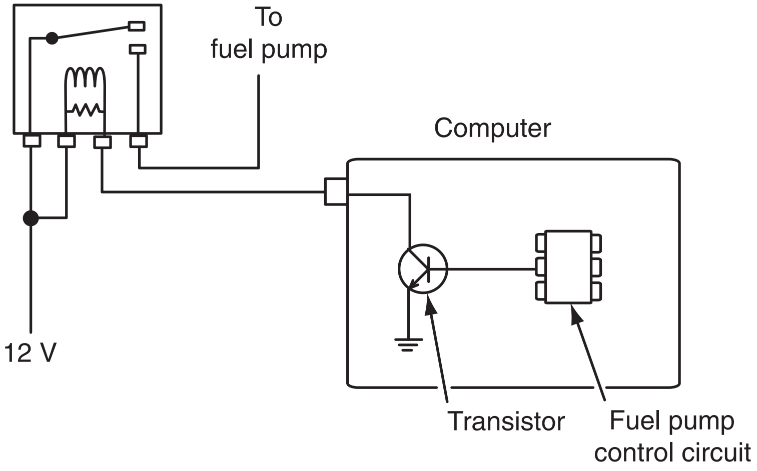


Figure 3–29 Typical fuel pump relay circuit.

If this seems confusing when compared to N/C and N/O solenoids discussed in the previous paragraphs, remember that a *valve* must be *open* to allow flow of whatever it controls and a *switch* must be *closed* to allow current to flow across its contacts.

Electric Motors

When electric motors are used as actuators, two unique types are used.

Stepper Motors. A stepper motor, as used in these applications, is a small electric motor powered by voltage pulses. It contains a permanent magnet armature with either four or two field coils (Figure 3–30). In the design with four field coils, all coils receive battery voltage and the computer completes the ground paths, one at a time, to pulse current to each coil in sequence. In the design with two field coils, the computer not only pulses current to energize each coil in sequence, but it can also reverse the polarity applied to each coil as part of the sequencing. Each time the computer pulses current to a field coil, it causes the stepper motor to turn a specific number of degrees. In either design, reversing this sequence causes the stepper motor

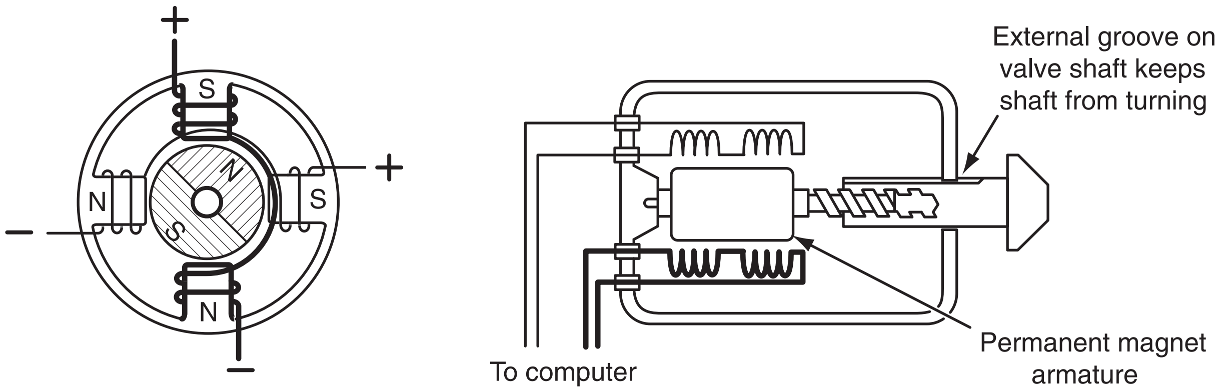


Figure 3–30 Typical stepper motor with two field coils.

to turn in the opposite direction. Ultimately, a stepper motor is controlled by the computer to turn a number of specific steps or increments, with the direction being controlled by the sequencing of the current pulses to the windings.

The armature shaft usually has a spiral on one end that connects to whatever the motor is supposed to control. As the motor turns one way, the controlled device (a pintle valve, for instance) is extended. As it turns the other way, the valve is retracted. The computer can apply a series of pulses to the motor's coil windings to move the controlled device to whatever location is desired. The computer can also know exactly what position the valve is in by keeping count of the pulses applied. Stepper motors have been used with feedback carburetors as a method of controlling the air/fuel ratio. They are also used with fuel injection systems as a method of controlling idle speed.

Permanent Magnet Field Motors. Some systems use this type of motor to control idle speed (Figure 3–31). It is a simple, reversible DC motor with a wire-wound armature and a permanent magnet field. The polarity of the voltage applied to the armature winding determines the direction in which the motor spins. The armature shaft drives a tiny gear drive assembly that either extends or retracts a plunger. The plunger contacts the throttle linkage. When it is extended, the throttle blade opening is increased; when it is retracted, the throttle blade opening is decreased. The computer has the ability to apply a continuous voltage to the armature until the desired idle speed is reached.

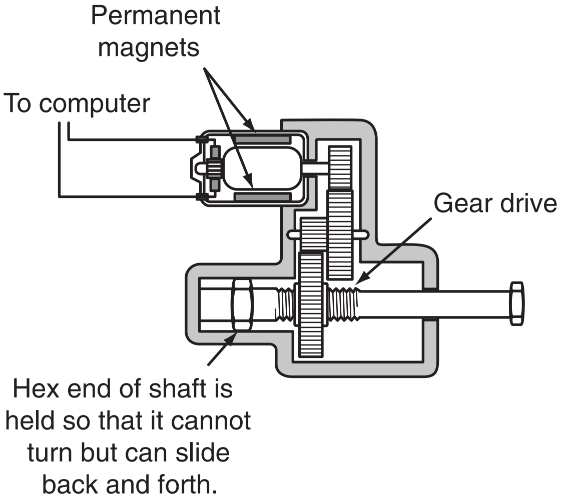

Permanent magnets
To computer
Gear drive
Hex end of shaft is held so that it cannot turn but can slide back and forth.

Figure 3–31 Permanent magnet field reversible DC motor.

✔ SYSTEM DIAGNOSIS AND SERVICE

Pre-Checks and Visual Inspection

Many problems that are responsible for a symptom can be found easily if the technician conscientiously and purposefully inspects certain aspects of the problematic system. These pre-checks should include the following four checks:

1. A visual check of all wiring and connectors associated with the system. Look for wires that have rubbed against a component or a bracket and worn through the insulation to the copper. Also check for wires that stretch when you pull them between your fingers—this always indicates broken copper inside the wire, usually due to constant flexing (sometimes due to the movement of the transverse mounted engine as the vehicle shifts gears).
2. Check all fuses electrically and visually. A visual check may find one leg of a fuse that is corroded where it connects to the fuse socket. Do not rely on a visual check only, however; also perform an electrical check, using a grounded wired or wireless test light with the fuse powered up. Both ends of the fuse should illuminate the grounded test light. Some glass tube fuses will crack under a metal end cap where you may not see it in a visual inspection; this author has seen at least one ATO spade-style fuse that looked okay visually but did not have electrical continuity through it. Also, most fuses provide power for

multiple circuits (usually between 3 and 7), not just the primary circuit that it is labeled for at the fuse box. Many times this information is provided in the vehicle's owner's manual. So don't just test the one fuse you think is associated with the problem system, but take a minute or two and test all of the fuses.

3. Visually inspect any other components associated with the problem system.
4. Take the time to listen for vacuum leaks in the engine compartment and under the instrument panel with the engine running. While vacuum control is not as prevalent on modern vehicles as it was in the 1970s and 1980s, there are still a few vacuum-operated systems, including the positive crankcase ventilation (PCV) system, the canister purge and evaporative system, and, on many vehicles, the EGR system; these systems are discussed further in Chapter 4. Also, some speed control systems continue to be vacuum operated. If a vacuum diaphragm ruptures, it will have multiple effects, as follows:
    - The component with the ruptured vacuum diaphragm will not operate properly.
    - Other components on the same vacuum line will not operate efficiently.
    - The vacuum leak will affect the air/fuel ratio by creating a lean condition.

Vacuum leaks on a speed density system with a MAP sensor will immediately cause a high idle RPM as the PCM will add fuel to the additional intake air. Vacuum leaks downstream from the MAF sensor on a multipoint injection system will initially cause a lean condition, resulting in a poor idle (if the engine idles at all, depending upon the severity of the vacuum leak). In time the PCM's fuel trim program (see Chapter 4) will learn to add fuel to the additional intake air and a high idle RPM will also result.

These pre-checks will not always identify the problem for you, but on many jobs, as most experienced technicians have learned, just a few minutes of conscientious checks have the potential to save an hour or so of diagnostic time.

Essential Diagnostic Tools

Service Manual. A good service manual that applies specifically to the vehicle being serviced is essential. It should contain all the necessary charts, electrical schematics, and diagnostic procedures. It should also list other tools necessary for diagnostic operations. Most modern service manuals are in electronic form, including such after-market programs as *Snap-on Shop Key, Mitchell On-Demand,* and *AllData*.

Scan Tool. Many older vehicles and all modern vehicles have a data link connector. Originally used in the factory to test the system's operation as it left the assembly line, this connector also provides dealership scan tool connectivity. Several after-market companies manufacture and sell scan tools that can connect to the data link connector to get service codes and data stream information from the computer. This information is typically shown as a digital readout on the scan tool and may also be printed out on paper. A scan tool is essential for system diagnosis; this is covered in more depth in Chapter 6.

Exhaust Gas Analyzer. While an exhaust gas analyzer is not a pinpoint test tool, it can be used to help you quickly narrow down the type of problem that you are chasing. Exhaust gas analysis is discussed further in Chapter 7.

High-Impedance Digital Volt-Ohm Meter (DVOM). When performing pinpoint tests on modern systems, a high-**impedance** DVOM is required for two reasons:

1. A DVOM is able to display readings with a higher degree of accuracy than can be obtained by reading a needle position on the scale of an analog meter.
2. Many circuits on modern vehicles have very high resistance and very low amperage values. Applying a standard analog meter with its relatively low internal resistance to such a circuit can easily constitute a short to the circuit. In other words, the meter's circuit offers an easier electrical path than the

circuit or portion of the circuit being tested. A high-impedance DVOM has a minimum of 10 million ohms of internal resistance; most standard analog meters have an internal resistance of between 10,000 and 300,000 Ω.

A DVOM is essential to system diagnosis; it is covered in more depth in Chapter 6.

Lab Scope or Digital Storage Oscilloscope (DSO). A lab scope or digital storage oscilloscope (DSO) can aid the technician in the pinpoint testing of a system by showing voltage and current waveforms over a period of time—something a DVOM cannot do. Lab scopes are discussed in more depth in Chapter 6.

Avoid Damaging the Computer

Many times a computer becomes damaged while the vehicle is in the service bay or as a result of something a technician either did or overlooked. When servicing a vehicle with a computerized engine control system, observe the following recommendations to reduce the potential for damage to the computer:

- Avoid starting the vehicle with the aid of a battery charger. Finish charging the battery first, and then disconnect the charger before starting.
- Turn the ignition off before disconnecting the battery or computer connectors.
- Replace any system actuator with less than specified resistance or one that has a shorted spike suppression (clamping) diode.
- Be sure that the winding of any electrical accessory added to the vehicle has sufficient voltage spike suppression capability. A resistor of 200 Ω to 300 Ω capacity can be used instead of a diode in some cases.
- Use caution when testing the charging system, and never disconnect the battery cables with the engine running.
- Wear a grounding strap when handling computers and other electronic parts. This reduces the chance of building up an electrostatic discharge (ESD) that might damage the computer.
- When jump starting:
    A. Turn the ignition off on the disabled vehicle.
    B. Turn the ignition off on the donor vehicle and turn on the headlights, blower motor, and rear window defogger. This reduces the battery voltage of the donor vehicle and reduces the potential for voltage spikes.
    C. Connect the jumper cables, paying very close attention to polarity. Make the final connection to a ground away from the vehicle's battery.
    D. Turn off the headlights, blower motor, and rear defogger on the donor vehicle, allowing the battery voltage to come up. Then start the engine of the donor vehicle, which will raise the voltage to charging system voltage.
    E. Attempt to start the engine of the disabled vehicle. Do not connect and reconnect the jumper cables at this time—you can produce voltage spikes that will damage the on-board computers. If a connection needs to be re-made, repeat steps 1 through 4.

SUMMARY

We have learned how the computer system's most important sensors work, including variable resistors, NTC thermistors, and signal generators. The zirconium oxygen sensor produces a voltage corresponding to the amount of oxygen remaining in the exhaust gas; temperature sensors modify a reference voltage to match their temperature; and the throttle position sensor varies its return voltage signal through a variable potentiometer, so the computer knows exactly where the throttle is and how quickly it is moving.

We reviewed magnetic sensors, Hall effect sensors, and optical sensors. Permanent magnet

Diagnostic & Service Tips

Oxygen Sensor. When handling or servicing the oxygen sensor, several precautions should be observed:

- A boot is often used to protect the end of the sensor where the wire connects. It is designed to allow air to flow between it and the sensor body. The vent in the boot and the passage leading into the chamber in the oxygen-sensing element must be open and free of grease or other contaminants.
- Sensors with soft boots must not have the boot pushed onto the sensor body so far as to cause it to overheat and melt.
- No attempt should be made to clean the sensor with any type of solvent.
- Do not short the sensor lead to ground, and do not put an ohmmeter across it. Any such attempt can permanently damage the sensor. The single exception is that a digital high-impedance (10 megaohm minimum) voltmeter can be placed across the sensor lead to ground (the sensor body).
- If an oxygen sensor is reinstalled, its threads should be inspected and cleaned if necessary with an 18 mm spark plug thread chaser. Before installation, its threads should be coated with an antiseize compound, preferably liquid graphite and glass beads. Replacement sensors may already have the compound applied.

WARNING: It is often recommended that the oxygen sensor be removed while the engine is hot to reduce the possibility of thread damage. When doing so, wear leather gloves to prevent burns on the hand.

sensors use a magnet and a coil to produce an alternating current, the frequency of which corresponds to the speed of a crankshaft or camshaft. The Hall effect sensor functions basically as an on-off switch, signaling the same sort of information. Optical sensors generate voltage signals in a fashion similar to a Hall effect sensor, except that they use a photocell opposite an LED.

We have also seen how simple on-off switches can provide information on parameters such as the engagement or disengagement of the air-conditioner compressor, or what gear an electronic automatic transmission is in. Finally, we have seen how the computer controls actuators, including a look at the operation of N/C and N/O solenoid-operated valves, N/C and N/O relays, and motors.

▲ DIAGNOSTIC EXERCISE

A car is brought into the shop with various running and driveability concerns. Among the things the technicians notice is a great deal of rust throughout the car, including on the connections for the electrical system. What kinds of problems would you anticipate might occur as a result of this kind of excessive rust formation? How would you check circuits to see how much, if at all, they were affected? How would you correct the electrical resistance problems that would occur from the rust?

Review Questions

1. Technician A says that most often the computer is designed to control the ground side of an actuator, although there may be an occasional exception. Technician B says that most often the engine computer is located in the trunk or luggage compartment of the vehicle. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

2. With few exceptions, the reference voltage that engine computers send to the sensors is equal to which of the following?
   A. 1 V
   B. 5 V
   C. 12.6 V
   D. 14.2 V
3. Which of the following sensors may produce or generate a voltage signal?
   A. Oxygen sensor
   B. Thermistor
   C. Potentiometer
   D. Piezoresistive silicon diaphragm
4. Zirconium dioxide is a substance that is found in which of the following?
   A. Oxygen sensor
   B. Throttle position sensor
   C. Engine coolant temperature sensor
   D. Manifold absolute pressure sensor
5. During closed-loop operation, the engine computer attempts to cause the oxygen sensor to average which of the following?
   A. 100 mV
   B. 450 mV to 500 mV
   C. 900 mV
   D. 5 V
6. Technician A says that as the temperature of an NTC thermistor increases, its resistance decreases. Technician B says that the engine computer monitors the voltage drop across an NTC thermistor in a temperature-sensing circuit in order to know the measured temperature. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
7. Technician A says that a temperature-sensing circuit is a current-divider circuit and that the sensor is an NTC thermistor placed in parallel to a fixed resistance within the computer. Technician B says that a temperature-sensing circuit is a voltage-divider circuit and that the sensor is an NTC thermistor placed in series to a fixed resistance within the computer. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
8. A sensor that varies resistance to measure the physical position and motion of a component would be which of the following?
   A. Thermistor
   B. Potentiometer
   C. Piezoresistive silicon diaphragm
   D. Piezoelectric crystal
9. If a temperature-sensing circuit with an NTC thermistor were to develop an electrical open, the computer would see which of the following?
   A. About –40°F
   B. About 0°F
   C. About 150°F
   D. About 212°F
10. If a circuit with a potentiometer were to develop an electrical open in the ground wire, which of the following would be true concerning the voltage that the computer sees?
    A. It would be steady at zero volts.
    B. It would be steady at 2.5 V (1/2 of reference voltage).
    C. It would be steady at 5 V (reference voltage).
    D. It would vary normally with the mechanical position of the sensor.
11. The speed density formula is a method of which of the following?
    A. Calculating how much air is entering the engine
    B. Measuring how much air is entering the engine
    C. Calculating how much fuel is entering the engine
    D. Measuring how much fuel is entering the engine
12. Technician A says that exhaust gasses that are metered into the intake manifold by the EGR valve reduce the amount of ambient air that gets into the cylinders. Technician B says that some engine computers use sensors to determine EGR flow rates, while others assume EGR flow rates by using estimates of

EGR flow that are stored in a computer memory. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

13. Which of the following sensors is used to measure the amount of intake air by measuring the cooling effect of the air that is entering the engine?
    A. Oxygen sensor
    B. NTC thermistor
    C. MAP sensor
    D. MAF sensor

14. Technician A says that a Hall effect switch may be used to sense crankshaft position and RPM. Technician B says that an optical sensor may be used to sense crankshaft position and RPM. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

15. An optical sensor consists of all except which of the following?
    A. Permanent magnet
    B. Photocell
    C. Slotted wheel
    D. Light-emitting diode

16. What is a detonation sensor (knock sensor)?
    A. A thermistor
    B. A potentiometer
    C. A piezoresistive silicon diaphragm
    D. A piezoelectric crystal

17. Technician A says that when a switch is closed in a pull-down circuit, it will apply battery voltage to a computer input. Technician B says that when a switch is closed in a pull-up circuit, it will apply a ground to a computer input. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

18. If a solenoid is turned on and off rapidly but there is no set number of cycles per second, what is its on-time referred to as?
    A. Percent duty cycle
    B. Pulse width
    C. Frequency
    D. Capacitance

19. Technician A says that an N/O solenoid-operated valve must be de-energized to allow flow through it. Technician B says that an N/O relay must be energized to allow current flow through it. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

20. Technician A says that a stepper motor can be used to control the air/fuel mixture in a feedback carburetor. Technician B says that idle speed can be controlled with either a stepper motor or a permanent magnet field motor. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

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Chapter 4

Common Operating Principles for Computerized Engine Control Systems

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Describe the difference between return-type and returnless fuel injection systems.
- ☐ Interpret fuel trim values during diagnosis with a scan tool.
- ☐ Describe the three levels of information available to a powertrain control module (PCM) regarding crankshaft position and camshaft position.
- ☐ Understand the purpose of crankshaft position sensors versus camshaft position sensors.
- ☐ Recognize the purpose and function of various emission-control systems.

KEY TERMS

Camshaft Position (CMP) Sensor
Catalyst
Crankshaft Position (CKP) Sensor
Distributor Ignition (DI)
Electronic Ignition (EI)
Electronic Returnless Fuel Injection
Fuel Trim
Grounded Shield
Long-Term Fuel Trim (LTFT)
Modulate
Palladium
Platinum
Returnless Fuel Injection
Return-Type Fuel Injection
Rhodium
Short-Term Fuel Trim (STFT)
Vapor Lock
Volatility
Waste Spark

Understanding the product-specific system designs in the manufacturer-specific chapters of this textbook may seem to be a difficult task, but all these methods are based on a few common operating principles. This chapter covers some of the basic, but often misunderstood, concepts that are used by all manufacturers. Understanding the material in this chapter will help your understanding of the manufacturer-specific chapters.

ELECTRONIC FUEL INJECTION SYSTEM OPERATING PRINCIPLES

Fuel Injector Design and Operation

Fuel injectors are nothing more than solenoid-operated valves that are spring-loaded normally closed (N/C) and that spray fuel when electrically energized. Because the injector is under pressure, fuel will spray in a highly atomized pattern each time the injector is energized by the computer. The injector's electromagnetic winding, or coil (Figure 4–1), is also kept immersed in liquid fuel that carries away heat, preventing overheating of the winding; such overheating could result in a short between coils of the winding. The injector has a screen at its inlet to keep any foreign particles from entering the injector. An injector may be designed for use with either high-pressure or low-pressure

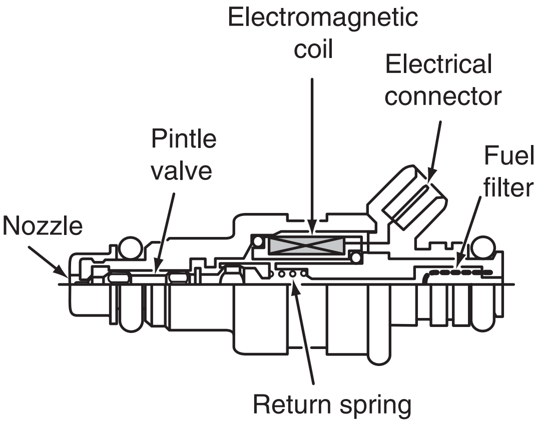


Figure 4–1 Typical high-pressure fuel injector.

fuel injection systems (Figures 4–1 and 4–2). Most fuel injectors are pintle-and-seat designs; the pintle blocks fuel flow when de-energized and protrudes slightly through the seat's orifice. Some low-pressure injectors are designed with a ball valve that seats on six small orifices when de-energized (Figure 4–2). Fuel injectors are rated for flow rate. The required flow rate is determined by engine displacement, volumetric efficiency (VE), and whether the injection system is a throttle body or multipoint system design. (Multipoint injectors have a lower flow rate than do throttle body injectors.)

The engine computer, or powertrain control module (PCM), controls the fuel injectors on a pulsed signal. This is known as the injector's *pulse width*. Pulse width is similar to duty cycle, except that duty cycle has a fixed cycling rate or frequency. The frequency of a fuel injector's pulse is indexed to the frequency of the ignition system's tach reference signal and will increase in frequency as engine RPM is increased.

Standard Fuel Injectors. Standard fuel injectors, used on most multipoint fuel injection systems, have an internal winding resistance of between 12 and 22 Ω (typical). These are energized by the computer using a single driver (transistor) to complete the ground path for the duration of the pulse (Figure 4–3). Figure 4–4

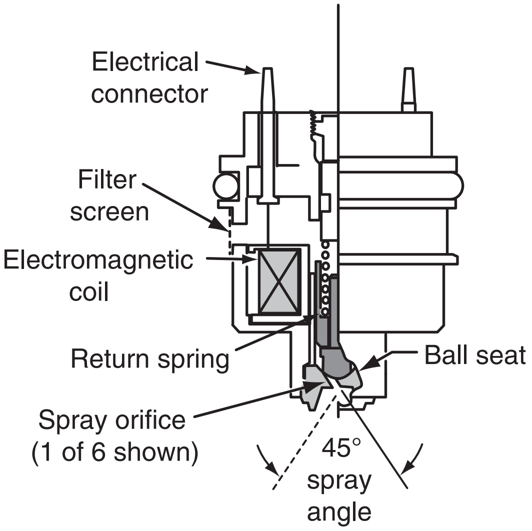


Figure 4–2 Low-pressure fuel injector.

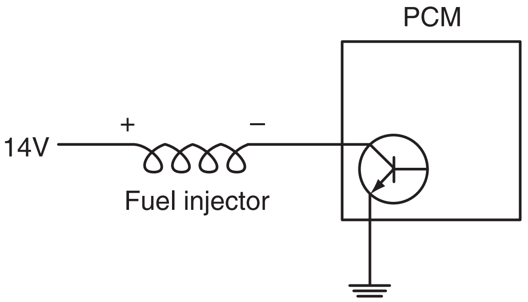


Figure 4–3 A standard injector's driver circuit.

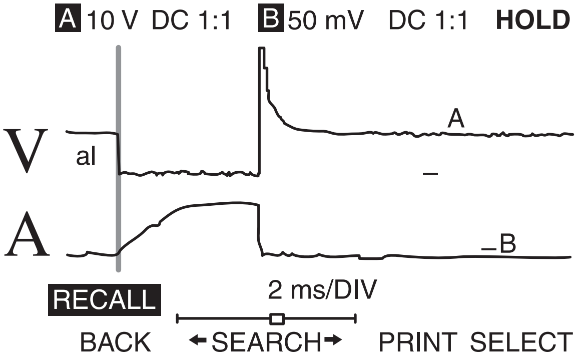


Figure 4–4 Voltage and current waveforms for a standard fuel injector.

shows the typical voltage and current waveforms for a standard fuel injector.

Peak and Hold Injectors. Most throttle body systems (and a few multipoint systems) use a low-resistance fuel injector, known as a *peak and hold injector*. These injectors have only 2 to 3 Ω of resistance in the winding and are capable of nearly 5 amps of current flow. This allows the injector to be opened more quickly to keep up with the tach reference pulses of the ignition system. This is most critical with throttle body systems in which the fuel injector is pulsed once for each tach reference pulse, as opposed to those systems in which an injector is pulsed once each one or two crankshaft revolutions. Peak and hold injectors are controlled by two drivers (Figure 4–5): One provides a direct path to ground; the other provides a path to ground through a resistor that is inside the computer. Both drivers are forward biased to initially energize the injector; then the one with the direct path to ground is released, leaving current to continue to flow through the remaining circuit with the resistor. This allows maximum initial current flow through the fuel injector, resulting in good mechanical response. Once the injector has been opened, however, current flow is immediately reduced to approximately 1 amp or less for the duration of the pulse to prevent overheating of the injector's winding. These circuits are known as the injector's "peak" and "hold" circuits. Figure 4–6 shows the typical voltage and current waveforms for a peak and hold fuel injector.

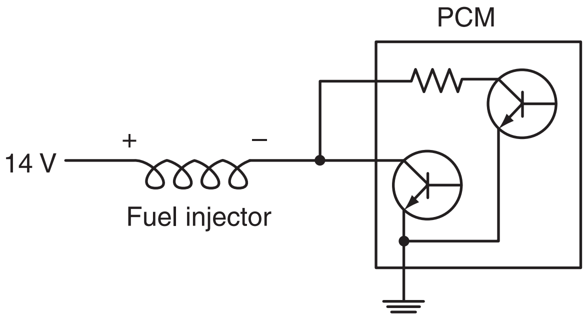


Figure 4–5 A peak and hold injector's driver circuit.

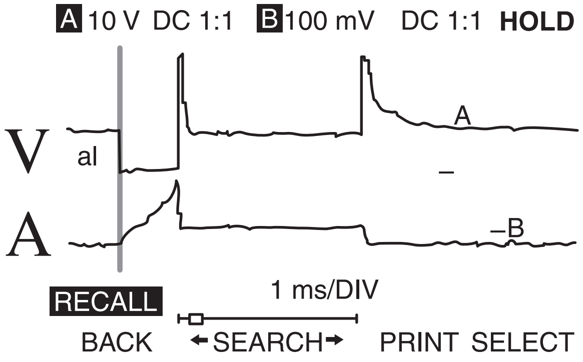


Figure 4–6 Voltage and current waveforms for a peak and hold injector.

Current-Controlled Injectors. Current-controlled injectors are similar in purpose and operation to peak and hold injectors except that a single driver is used to control them. Initially, full current is allowed to flow through the injector's winding for good mechanical response. Once the injector is open, the computer rapidly duty cycles the driver to reduce the average current to approximately 1 amp or less to prevent overheating of the winding. This style tends to be found on some Asian throttle body and port fuel-injected applications. Figure 4–7 shows the typical voltage and current waveforms for a current-controlled fuel injector.

Injectors with an External Resistor. Some applications design a low-resistance injector in

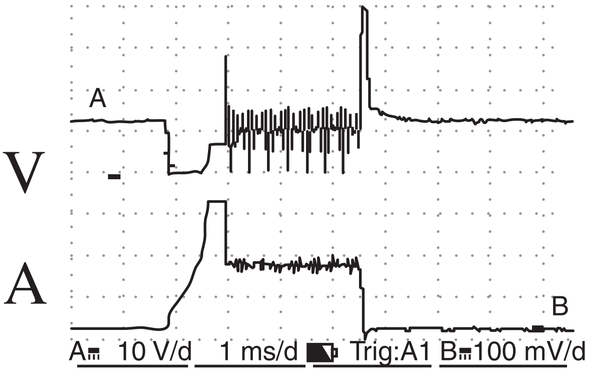


Figure 4–7 Voltage and current waveforms for a current-controlled injector.

series with an external resistor to limit current flow. Check the electrical schematic to identify systems of this type. When testing any fuel injector for proper resistance in the winding, always use the resistance specifications from the service manual.

Fuel Injection System Types

There are two types of fuel injection systems used with comprehensive computerized engine control systems: single point and multipoint. They each use an intermittently pulsed and timed spray to control fuel quantity. (There is one exception: the Bosch K-Jet systems, described more fully in the European systems chapter of this book.)

Single-Point Injection. Single-point injection is often referred to as *throttle body injection* (TBI). Single point means that fuel is introduced into the engine from one location. This system uses an intake manifold similar to what would be used with a carbureted engine, but the carburetor is replaced with a throttle body unit (Figure 4–8). The throttle body unit contains one or two solenoid-operated injectors that spray fuel directly over the throttle plate (or plates). Fuel under pressure is supplied to the injector. The throttle plate is controlled by the throttle linkage, just as in a carburetor. The computer controls voltage pulses to the solenoid-operated injector, which opens and sprays fuel into the throttle bore. The amount of fuel introduced is controlled by the length of time the solenoid is energized. This is referred to as the injector's pulse width. The amount of air introduced is controlled by the opening of the throttle plate(s); it is also affected by any air that is introduced by the idle air control valve (IACV).

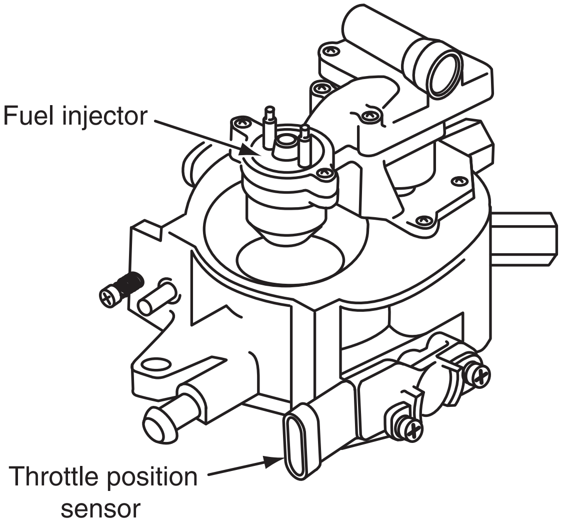


Figure 4–8 TBI unit.

A TBI system is characterized by excellent throttle response and good driveability, especially on smaller engines. Experience has shown, however, that the system is best suited for engines with small cross-sectional area manifold runners that at low speeds will keep the fuel mixture moving at a high velocity. This reduces the tendency for the heavier fuel particles to fall out of the air stream.

Multipoint Injection. In a multipoint injection (MPI) system, often referred to as port fuel injection (PFI), fuel is introduced into the engine from more than one location. This system uses an injector at each intake port. Fuel is sprayed directly into the port and directly onto the back side of the intake valve.

The MPI/PFI system provides the following advantages:

- Spraying precisely the same amount of fuel directly into the intake port of each cylinder eliminates the unequal fuel distribution inherent when already mixed air and fuel are passed through an intake manifold.
- Because there is no concern about fuel condensing (puddling) as it passes through the intake manifold, there is less need to heat the air or the manifold.
- Because there is no concern about fuel molecules falling out of the air stream while moving through the manifold at low speeds, the cross-sectional area of the manifold runners can be larger and thus offer better cylinder-filling ability or VE at higher engine speeds. Some manufacturers have designed variable-geometry intake runners to optimize air ingestion at different engine speeds and loads.

- Most of the manifold-wetting process is avoided, though some wetting still occurs in the port areas and on the valve stems. If fuel is introduced into the intake manifold, some will remain on the manifold floor and walls, especially during cold engine operation and acceleration. Fuel metering has to allow for this fuel to avoid an overly lean condition in the cylinders. It has to be accounted for again during high-vacuum conditions because under such conditions it will begin to evaporate and go into the cylinders.

In general, PFI provides better engine performance and excellent driveability while maintaining or lowering exhaust emission levels and increasing fuel economy. The major disadvantages are somewhat greater cost and reduced serviceability because of the larger number of components and their relative inaccessibility.

Additionally, while many early PFI systems used various firing strategies for the fuel injectors that grouped them together in pairs, banks, or groups with all injectors being pulsed together, in most modern PFI systems the PCM will pulse the injectors individually in the engine's firing order, just before the intake valve opens. This is generally referred to as *sequential fuel injection* (SFI) or *sequential multipoint injection* (SMPI) (Figure 4–9).

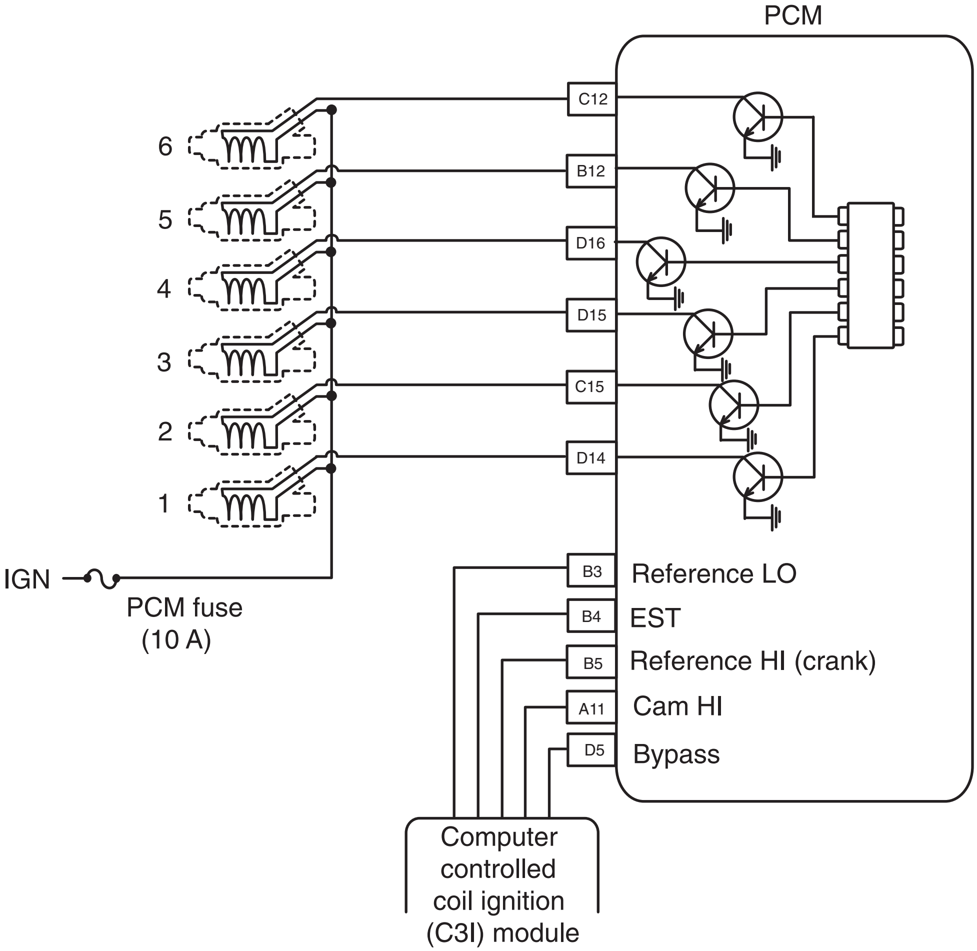


Figure 4–9 Electrical schematic for a typical SFI circuit.

Electric Fuel Pumps

The electric fuel pumps used with electronic fuel injection systems are most often mounted in the fuel tank (Figure 4–10), which reduces the potential for **vapor lock.** These pumps are highly capable, being designed to develop more pressure than the system's working pressure (as regulated by the pressure regulator). A few vehicles use more than one fuel pump, locating one in the fuel tank and an additional high-pressure pump in the fuel supply line. The fuel pump contains a check valve, which prevents fuel pressure from pushing fuel already in the supply line back into the fuel tank during engine shutdown. This, combined with the pressure regulator, allows the system to hold residual pressure until the next time the engine is started.

Electric fuel pumps are not directly controlled by the PCM, but rather are controlled by the PCM via a fuel pump relay, which carries the higher current flow. This relay is energized by the PCM whenever the PCM is receiving a tach reference signal from the ignition system. The relay is

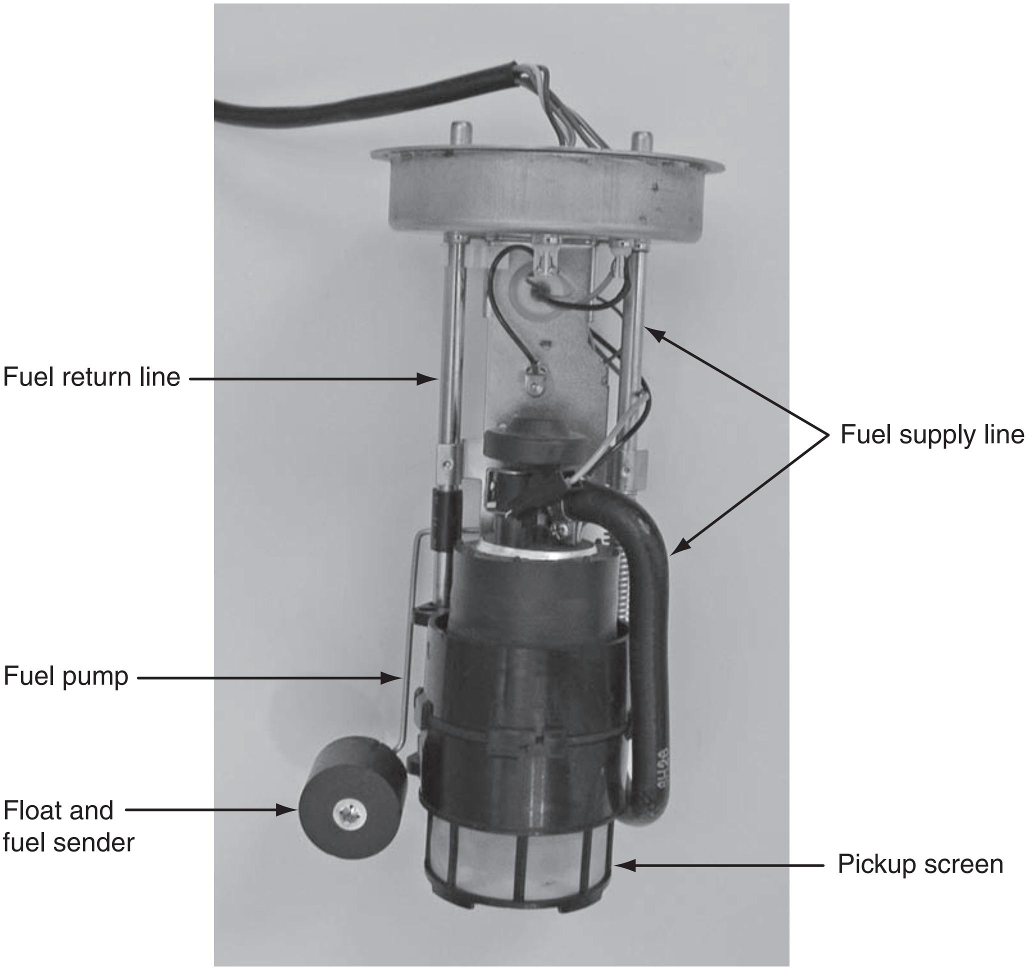


Figure 4–10 An in-tank electric fuel pump.

de-energized if the tach reference signal to the PCM is lost. There is only one exception to this: The fuel pump relay will be energized by the PCM for approximately 2 seconds whenever the ignition switch is first turned on and the PCM is initially powered up, whether or not a tach reference signal is present. (This occurs provided the ignition switch has been turned off long enough to allow the PCM to power down—about 8 seconds on those vehicles that use a motor or stepper motor to control idle speed. This type of actuator must be reset by the PCM after the ignition is turned off.) Manufacturers are thus able to protect an unconscious driver from a system that might otherwise empty the fuel tank on the ground through a ruptured fuel supply line following an accident: If the fuel supply line ruptures, fuel pressure is immediately lost, the engine immediately stalls, and the tach reference signal to the PCM is lost, resulting in the PCM de-energizing the fuel pump relay.

Fuel Pressure Regulator Design and Operation

A fuel pressure regulator is a simple, spring-loaded, N/C bypass valve, which allows the system to maintain proper fuel pressure at the fuel injector(s). The pressure regulator is located *after* the fuel injector(s) (or, in a returnless system, after the supply line that feeds the injectors) so as to keep the fuel injector(s) pressurized at the inlet screen (Figure 4–11).

Return-Type Fuel Injection Systems

As manufacturers began replacing carburetors with electronic fuel injection systems, system features that had been used with carbureted engines to reduce the potential for vapor lock also made their way into fuel injection system designs. *Vapor lock* is defined as the vaporization of fuel within the confines of the fuel management system. This will typically result in engine stall due

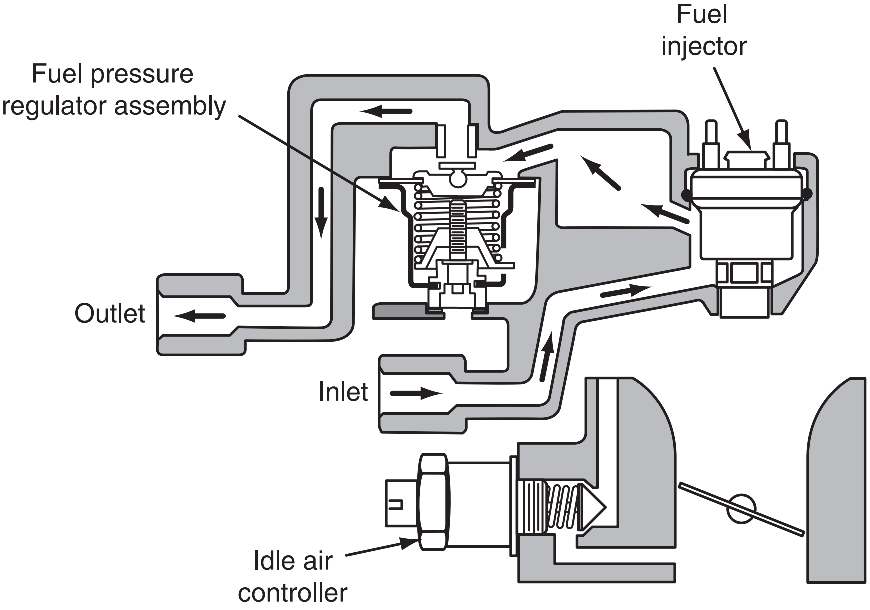


Figure 4–11 Fuel pressure regulator.

to the fact that none of our fuel management systems are capable of supplying enough fuel volume in the form of a vapor to keep an engine running.

The primary factor in vapor lock is the fuel's **volatility.** Fuel that is highly volatile is easily vaporized, having a lower boiling point than fuel that is less volatile. A liquid's volatility is influenced by two factors: what type of liquid it is (for example, gasoline versus alcohol) and how much pressure is placed on it (reducing the pressure placed on a liquid increases its volatility).

Vapor lock is caused by fuel that is high in temperature combined with low pressure in the lines, particularly in the fuel pump suction line of a carbureted engine with a mechanical fuel pump located at the engine. If the fuel vaporizes within the lines, the engine will typically stall and will not restart until the hot fuel cools down enough to recondense back into a liquid.

Many carbureted systems began using *return lines* from the fuel pump (or from the fuel filter located near the carburetor) back to the fuel tank as a method of continually drawing cooler fuel from the tank. This helped to keep the temperature of the fuel in the line low enough to reduce the potential for vapor lock, even with low fuel consumption, such as might be experienced in heavy city traffic. These fuel return lines were carried over to most fuel injection systems. Another method of combating vapor lock involves *relocating the fuel pump* from the engine compartment into or near the fuel tank. This effectively raises the line pressure of the fuel supply line and thereby reduces the volatility of the fuel in that line. A third method is simply *raising the pressure placed on the fuel* in the fuel management system, something that modern fuel injection systems do quite effectively.

In a **return-type fuel injection** system (Figure 4–12), the fuel pump in the tank pushes the fuel through the fuel supply line and primary fuel filter, then past the inlets to the fuel injectors and to the fuel pressure regulator. When enough fuel pressure has developed underneath the regulator's seat to unseat it (against spring tension), fuel is allowed into the fuel return line that exits the pressure regulator, thereby allowing this excess fuel to return to the fuel tank.

Most fuel pressure regulators used on TBI systems use spring tension alone to regulate the pressure of the fuel at the fuel injectors, because

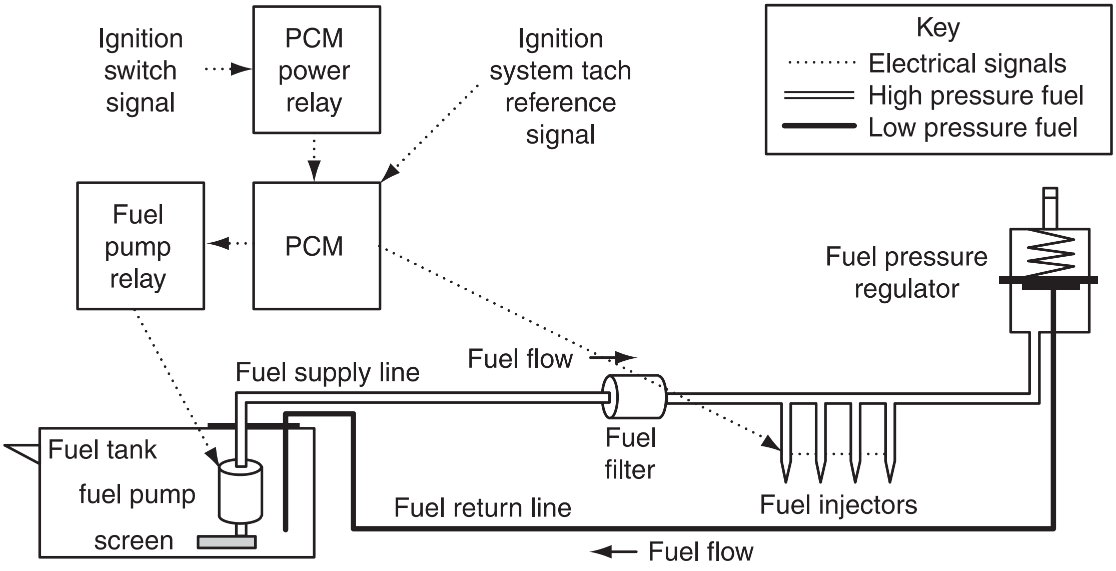


Figure 4–12 Return-type fuel injection system.

the fuel injector is designed to spray fuel above the throttle plate(s) and into an area that is very close to barometric pressure. Since this pressure near the outlet tip of the injector is relatively stable, the line pressure is held stable as well, resulting in a consistent pressure differential across the fuel injector and, therefore, a consistent flow rate. A few TBI systems allow atmospheric pressure to the spring side of the regulator, thereby allowing it to adjust fuel pressure slightly to compensate for barometric pressure changes. This increases the consistency of the pressure differential across the injector, regardless of changes in altitude or weather patterns.

In a return-type PFI system, because these injectors must spray fuel below the throttle plate(s) or into existing pressure within the intake manifold, the spring side of the pressure regulator is indexed to intake manifold pressure via a "vacuum hose." Consider how changes in intake manifold pressure would affect fuel delivery without this indexing (that is, with a fixed fuel rail pressure): At idle under light engine load, when there is reduced pressure within the intake manifold, the pressure differential across the injector would be greater, resulting in an increased flow rate when there is less need for fuel. Under heavy load, when intake manifold pressure is greater, the pressure differential across the injector would be reduced, resulting in a decreased flow rate when there is more need for fuel. When the spring side of the pressure regulator is indexed to intake manifold pressure, any change of pressure within the manifold causes an exactly equal change in fuel rail pressure. In actual operation, a low pressure (or vacuum) applied from the intake manifold to the spring side of the regulator results in an equal reduction in fuel rail pressure because the low-pressure signal helps the fuel pressure to unseat the valve. When a higher pressure (loss of vacuum) is applied from the intake manifold to the spring side of the regulator, fuel rail pressure is raised equally. This also holds true when boost pressure might be present within the intake manifold, resulting in an additional equal increase in fuel rail pressure. Therefore, when the spring side of the regulator is indexed to intake manifold pressure, the pressure differential across the fuel injectors is held constant, regardless of engine load. This results in a consistent flow rate whenever the PCM energizes the injector, regardless of engine load. As a result, the only real variable in controlling the quantity of fuel that is delivered to the cylinders is injector on-time—and this is the variable that is under PCM control. As a result, the PCM has complete control over the quantity of fuel that is delivered.

Returnless Fuel Injection Systems

Once manufacturers had successfully reduced the potential for vapor lock, their concerns turned to reducing the heat that return-type systems dump into the fuel tank—heat that increases the potential for evaporative hydrocarbon emissions. Most of this heat is picked up in the engine compartment by the excess fuel that is to return to the tank. As a result, in the mid- to late 1990s, many manufacturers began using **returnless fuel injection** systems that eliminate the return line from the engine compartment to the fuel tank (Figure 4–13). In reality, there is a short return line that originates at a pressure regulator. However the pressure regulator is either inside the fuel tank or near the fuel tank (for example, inside the fuel filter), thereby eliminating the return line coming from the engine compartment and eliminating the carrying of engine compartment heat back to the fuel tank.

The fuel line from the fuel pump carries fuel to a "tee" intersection. One line from this "tee" goes to the fuel pressure regulator, which, as in a return-type system, returns excess fuel to the fuel tank. The other line carries fuel through the fuel supply line to the fuel injectors in the engine compartment, after which it dead-ends. The fuel supply line is actually in parallel to the fuel line that goes to the pressure regulator. Therefore, it can be said that the regulator is located *after* the line teeing off to deliver fuel to the injectors and as a result allows the regulator to control the pressure in the supply line. One difference, though, is that the pressure regulator is no longer indexed to

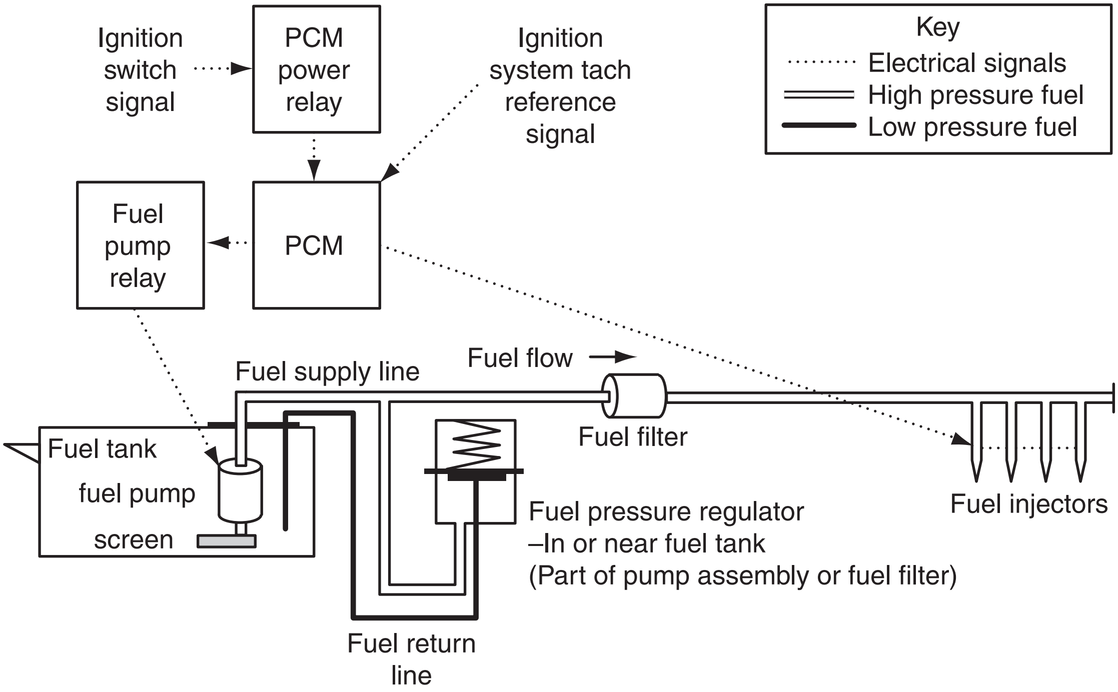


Figure 4–13 Returnless fuel injection system.

manifold pressure. A vacuum line from the engine compartment to the area of the fuel tank would be so long that the responsiveness of such a signal would be inadequate. Therefore, the line pressure is fixed and does not vary, but the resulting pressure differential across the fuel injectors does vary. Under light load the pressure differential across the injectors is greater; under heavy load the pressure differential across the injectors is less. Therefore, the PCM must both calculate the pressure differential across the injectors and compensate for changes in the differential with an adjustment of the injectors' pulse width.

A further adaptation of a returnless system is known as an **electronic returnless fuel injection** system (Figure 4–14), which allows the PCM to control the fuel supply line pressure by electronically controlling the speed of the fuel pump motor. A fuel pump relay supplies power to enable a fuel pump driver module (FPDM), usually located in the area of the vehicle's trunk. The FPDM carries the high current flow for the fuel pump in a manner similar to the fuel pump relay in the traditional system, but, because the transistor in the FPDM is solid state and therefore has no moving parts, it can be turned on and off many times faster than a mechanical relay. This characteristic allows the PCM to control the FPDM and therefore the fuel pump itself on a pulse width modulated (PWM) signal. The resulting average on-time of this pulse width signal ultimately controls the speed of the fuel pump motor and allows the PCM to control fuel rail pressure.

In an electronic returnless system, the PCM receives feedback from a pressure sensor on the fuel rail. This sensor not only measures fuel rail pressure, but also measures manifold pressure through a short vacuum hose attached to it. The fuel rail pressure sensor is actually a differential pressure sensor (see Chapter 3); it measures the difference between fuel rail pressure and intake manifold pressure. Ultimately, this sensor reports

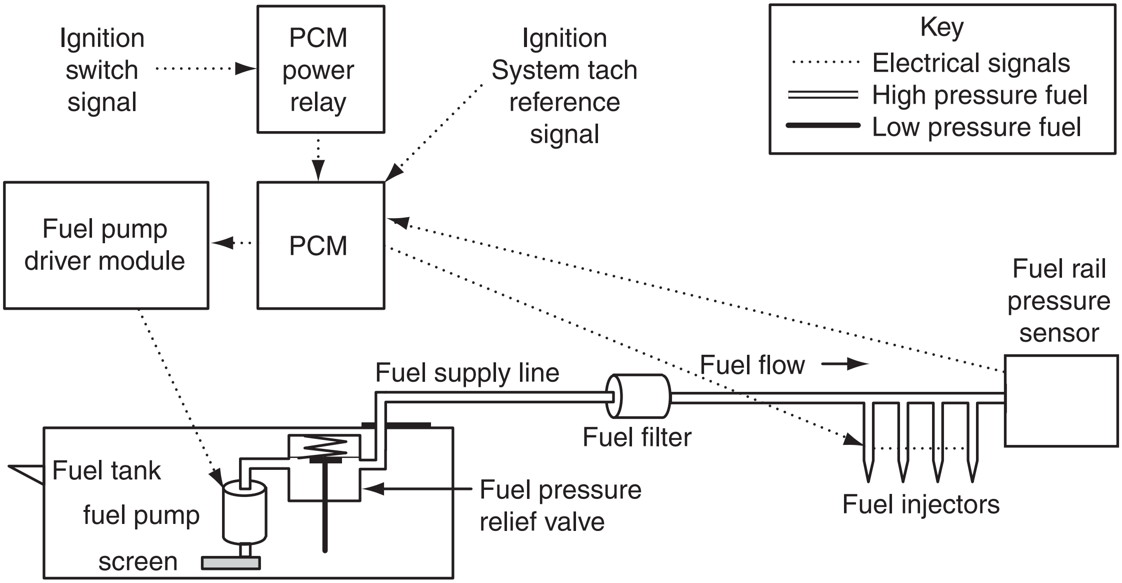


Figure 4–14 Electronic returnless fuel injection system.

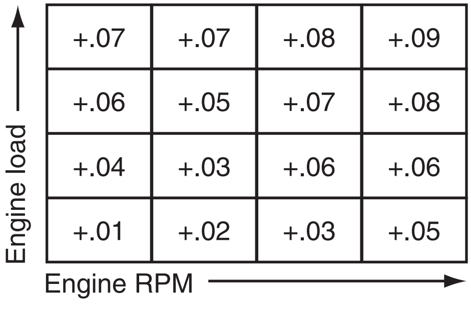
to the PCM the pressure differential across the fuel injectors, which defines the injectors' flow rate when energized. This allows the PCM to accurately calculate the injectors' required pulse width.

Fuel Trim

Fuel trim is a function programmed into the PCM on fuel-injected vehicles affecting the PCM's control of the air/fuel ratio. It is designed to allow the PCM to adjust the fuel injectors' pulse width to compensate for the wear and aging of components as they affect the air/fuel ratio. This is similar to the manner in which a PCM on a feedback-carbureted system is able to adjust the duty cycle to maintain a stoichiometric air/fuel ratio.

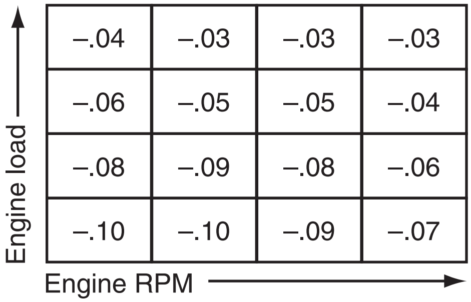
Fuel trim is divided into two parts: **short-term fuel trim (STFT)** and **long-term fuel trim (LTFT).** STFT is the immediate response to the last report from the oxygen sensor. LTFT is a long-term adjustment designed to keep the oxygen sensor averaging around the ideal 450 millivolts (mV). As a diagnostic aid, most applications allow the technician to look at both these values using a scan tool. Therefore, it is important that the technician understand how these functions affect the PCM's control of the air/fuel ratio.

Both fuel trims consist of electronic look-up tables (electronic charts) in the PCM's RAM memory chip. These look-up tables are divided (originally) into 16 cells (or blocks) that represent various combinations of engine load and RPM (Figures 4–15, 4–16, and 4–17). Modern systems


Engine load
Engine RPM

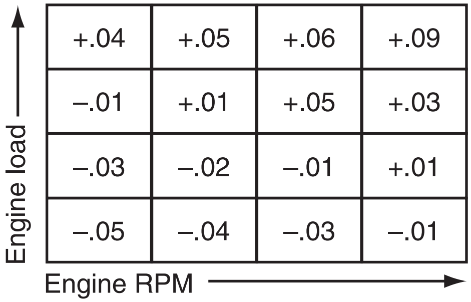
+.07	+.07	+.08	+.09
+.06	+.05	+.07	+.08
+.04	+.03	+.06	+.06
+.01	+.02	+.03	+.05

Figure 4–15 Fuel trim electronic look-up table indicating the PCM's response to an overall slightly lean condition.


Engine load
Engine RPM

–.04	–.03	–.03	–.03
–.06	–.05	–.05	–.04
–.08	–.09	–.08	–.06
–.10	–.10	–.09	–.07

Figure 4–16 Fuel trim electronic look-up table indicating the PCM's response to an overall slightly rich condition.


Engine load
Engine RPM

+.04	+.05	+.06	+.09
–.01	+.01	+.05	+.03
–.03	–.02	–.01	+.01
–.05	–.04	–.03	–.01

Figure 4–17 Fuel trim electronic look-up table indicating the PCM's response to a condition that is rich in the lower range and lean in the upper range, indicating multiple problems.

are likely to use a greater number of cells, not because the range of engine load or RPM has been extended, but in order to divide the original cells into smaller cells for more precise control of the air/fuel ratio. Most OBD II vehicles use the whole number "one" to represent the default neutral setting. This number originated as the Lambda value, a Greek symbol used to represent a stoichiometric air/fuel ratio (see Chapter 16). Prior to OBD II, some other values were used, depending upon the manufacturer. For example, pre-OBD II and some OBD II General Motors vehicles used the value "128" as the default neutral setting, derived from the mid-point value of an 8-bit computer (see the discussion of binary code in Chapter 2).

On an OBD II vehicle, the value in a given cell is shown as a percentage of the default value, either positive or negative. As an adjustment is made, this value can move either higher or lower. Positive percentages indicate that the PCM is adding fuel in response to a "lean report" from the oxygen sensor, and negative percentages indicate that the PCM is subtracting fuel in response to a "rich report" from the oxygen sensor.

When watching these values on a scan tool, the technician will find that STFT values will constantly change (along with oxygen sensor values) if the engine is running in a closed loop. In fact, not only is the STFT the immediate response to the oxygen sensor's last report, but the STFT adjustment is what will then cause the oxygen sensor to cross to the other side of the stoichiometric value. That is, the oxygen sensor and the STFT react to each other. It is this interaction that keeps the oxygen sensor cross-counting. LTFT, on the other hand, is a long-term adjustment that is designed to keep the oxygen sensor averaging around 450 mV (or, at least, between 400 and 500 mV) when STFT is operating in its normal operating range. Therefore, LTFT values, as seen on a scan tool, will tend to be stable, with minor changes occasionally occurring. If, while watching these values, you suddenly rev the engine, you will likely see the LTFT value change. But this change in LTFT is not likely the result of an actual change having occurred, but is, rather, the result of entering another cell of the look-up table as the engine was revved.

To demonstrate the operation of the fuel trim strategy, let us suppose that a vehicle is traveling at a steady speed, under a consistent load, with the engine fully warmed up and the system in closed loop and with all other inputs remaining constant (set at 60 mph on cruise control on a long, straight highway with no hills). The central processing unit (CPU) is preparing to turn on a fuel injector. It looks at all the input data that it has recorded in the RAM memory chip. It then looks up this combination of input values in the look-up tables that are programmed into the PROM memory chip (which is tailored to this particular vehicle) and comes up with a base fuel calculation.

Perhaps this base fuel calculation is a pulse width of 5.46 milliseconds(ms). The CPU then issues a command of 5.46 ms to the injector's output driver in the input interface.

As the exhaust gasses of the resulting air/fuel ratio, having combusted in the combustion chamber, reach the oxygen sensor, the sensor sends a report indicating "slightly rich" to the CPU. The CPU reacts to this by recording an STFT value in the RAM memory chip of –3 percent. The next time the CPU turns on the fuel injector, it still sees the same 5.46 ms as the base fuel calculation, but now it is also being instructed by the STFT value to subtract 3 percent, or 0.16 ms. So then the actual pulse width for the next injector firing is 5.30 ms. Of course, now the oxygen sensor sees this as being slightly lean and informs the CPU, which might store an STFT value of +3 percent. With the next injector firing, the CPU now takes the base fuel calculation of 5.46 ms and adds 3 percent or 0.16 ms to it and commands a total pulse width of 5.62 ms. As a result, the pulse width varies from 5.30 ms to 5.62 ms, and the oxygen sensor is cross-counting to maintain an average of about 450 mV as the system operates in closed loop. (The variance of the fuel injectors' pulse width can be seen on an oscilloscope and is indicative that the system is operating in a closed loop.)

Eventually, perhaps, a vacuum leak occurs. With everything continuing to operate as described, the CPU now notices that the oxygen sensor average is no longer close to 450 mV but is, instead, averaging only about 300 mV. The CPU now stores a +5 percent value in the LTFT. The next time the CPU calculates the fuel injector's pulse width, it uses the 5.46 ms base fuel calculation and still continues to use the STFT values, but now it also modifies the total pulse width by the LTFT value, which indicates that 5 percent of the base fuel calculation, or 0.27 ms, must be added. As a result, while operating in a closed loop, the pulse width is no longer varying between 5.30 ms and 5.62 ms but now is varying between 5.57 ms and 5.89 ms. Ultimately, a stoichiometric air/fuel ratio continues to be achieved, in spite of the vacuum leak.

A problem may become so severe that the PCM, while attempting to respond to it within the fuel trim program, simply cannot make a large enough adjustment, at which point the fuel trim values are said to have reached their threshold limits. In this scenario, the PCM will no longer be able to maintain a stoichiometric air/fuel ratio and emissions will increase. Driveability and fuel mileage will also likely be affected. By monitoring the fuel trim values with a scan tool, a technician can get some idea as to the types of problems to which the PCM has already responded or has attempted to respond.

Idle Speed Control

Manufacturers use two primary methods to achieve PCM control of the engine's idle speed. One method is to manipulate the physical position of the throttle plate(s). This concept began with feedback-carbureted systems and carried over into some fuel injection systems. This method worked well with feedback carburetors because as the PCM caused the throttle plate angle to change position, the carburetor automatically compensated with the correct amount of fuel. However, once this concept was applied to fuel injection (usually TBI systems), the fuel compensation was no longer automatic in that the PCM's adjustment of the throttle plate(s) was now only controlling airflow.

The other method is to leave the physical position of the throttle plate(s) at the hard stop screw setting (known as the *minimum airflow rate*) and, instead, control the volume of air that bypasses the throttle plate(s) (known as *throttle bypass air*). The actuator that the PCM uses to do this is typically either some form of a stepper motor adjusting a pintle's position or some form of N/C solenoid that is controlled by the PCM on either a duty cycle or a PWM command. Those solenoids that are operated on a duty cycle are controlled at a relatively low frequency (around 10 Hz), thus allowing the solenoid to completely open and close about 10 times per second while controlling the percentage of duty cycle on-time. Those solenoids that are operated on a PWM command are operated at a frequency typically between 800 Hz and 2500 Hz while the PCM controls the pulse width of the signal. The solenoid's valve does not actually open and close with each current pulse, but, rather, will float in a certain physical position according to the average current, thus allowing a certain amount of air to bypass the throttle plate(s). The various methods of controlling throttle bypass air are used in most modern fuel injection systems except for those newer systems that incorporate electronic throttle control (ETC) or "drive-by-wire."

In an ETC system, the idle speed actuator is eliminated because the PCM now has the ability to control the throttle plate angle directly. In a sense, ETC is a return to the original concept of manipulating the position of the throttle plate(s).

Fuel Injection System Design Summary

While there are many manufacturers, each producing many different models of vehicles, today's vehicles all use electronically controlled fuel injection systems that have common features, whether they are of U.S., European, or Asian design. The commonalities of all electronically pulsed fuel injection systems are these:

- The amount of fuel metered into the engine by the PCM is dependent upon how much air is entering the engine. The PCM knows this value either through a calculation known as the *speed density formula* or through a measurement using a mass air flow (MAF) sensor (see Chapter 3).
- PCM metering of the fuel into the engine is accomplished either with a return-type fuel injection system or with a returnless fuel injection system.

IGNITION SYSTEM OPERATING PRINCIPLES

Ignition Coil Design and Operation

Because it is critical to understand the operation of an ignition coil before proceeding, a quick description of operation will be given here. It is a voltage step-up transformer. It allows the primary winding to induce an intense voltage spike into the secondary winding. This voltage spike in the secondary winding becomes the spark to fire across the spark plug gap. To accomplish this, current flow is turned on and off in the primary winding. When current flow is turned on, the transistor (switch) in the primary circuit completes only the path for current to flow, thus allowing the voltage that is present to begin pushing current. (The transistor itself does not push current; rather, it only completes the circuit. Visualize the *opening* of a solenoid-operated valve that might control the flow of water. It only completes the path.) Thus, current flow builds to full saturation rather slowly (Figure 4–18). But when the transistor is turned off, the transistor itself forcibly stops current flow. (Visualize the *closing* of a solenoid-operated valve that might control the flow of water. Closing the valve forcibly stops the flow.) Therefore, current flow stops much more rapidly than it starts.

Each time current flow is turned on, relative motion exists between the resulting expanding magnetic field and the windings. Each time current flow is turned off, relative motion also exists

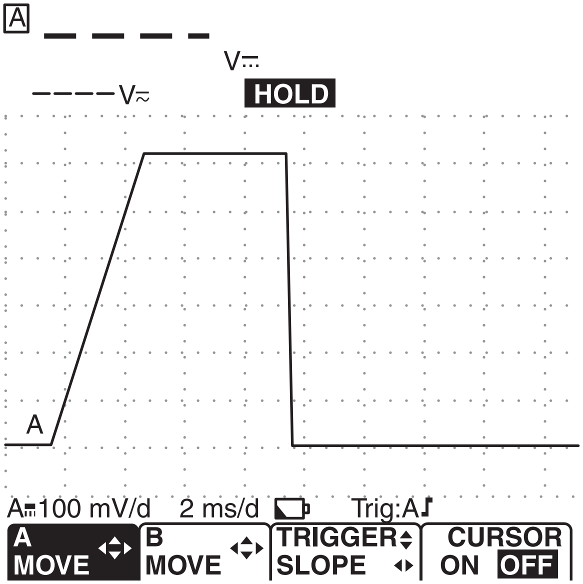


Figure 4–18 Current waveform for a typical ignition coil.

between the collapsing magnetic field and the windings. However, for this relative motion to induce a voltage spike (or voltage imbalance) in the windings, the relative motion must happen quickly. This speed is only achieved when the current flow is turned off, never when it is turned on. Therefore, electromagnetic windings produce voltage spikes only when the current flow is turned off.

In the case of an ignition coil, primary current flow is turned on in anticipation of when it will be turned off. When it *is* turned off, a voltage imbalance (voltage potential) is induced in both windings. The potential strength of this voltage spike is very low in the primary winding and is dissipated. But in the secondary winding, the potential strength of this voltage spike is much greater and will climb either to the coil's capacity or to the level that it needs to achieve to dissipate. The resistance in the secondary circuit determines this. A jumper wire placed between the secondary winding's negative and positive terminals would allow the excess of electrons (negative) to dissipate to the deficiency of electrons (positive) without much voltage buildup.

In the case of an ignition coil, a complete path must always exist for the secondary spark to flow, not only allowing electron flow from the negative end of the secondary winding but also back to the positive end of the secondary winding. Without this complete path, the voltage potential in the secondary winding would not cause the spark's electrons to flow. It is important at this point to understand that the secondary winding becomes a voltage source each time primary current flow is turned off.

Secondary Ignition System Types

There are three types of secondary ignition system designs. The first utilizes a single ignition coil to fire all cylinders. The spark from this single coil is distributed mechanically using a physical distributor. Thus, this system is known as a **distributor ignition (DI)** system. Both of the other types of ignition systems utilize multiple ignition coils, in which case the correct coil to be fired must be chosen electronically. Because the spark is said to be distributed electronically, these systems are referred to as **electronic ignition (EI)** systems.

In a DI system, the spark leaves the negative end of the coil primary winding and passes through the distributor and then to the spark plug. After jumping the spark plug gap to engine ground, it returns to the positive end of the secondary winding, either through the battery and positive primary circuitry or, if one is provided, through a more direct circuit.

In the first of the EI (or multiple coil) systems, known as a **waste spark** system, each coil is used to fire two spark plugs located on opposite (or companion) cylinders in the firing order. Each time a coil is fired, the spark leaves the negative end of the secondary winding and fires across one spark plug gap from the center electrode to the side electrode (Figure 4–19). (This plug is said to be firing *negatively* because the center electrode has a negative polarity.) Then the spark's electrons move through the metal of the engine block to the second plug that is wired in series with the first plug. This fires the second plug across the plug gap from the side electrode to the center electrode. (This plug is said to be firing *positively* because the center electrode has a positive polarity.) The spark then continues back to the positive end of the secondary winding, at which point the voltage imbalance of the secondary winding is fully dissipated. Each time the coil fires the two plugs, one of the cylinders will be approaching TDC near the end

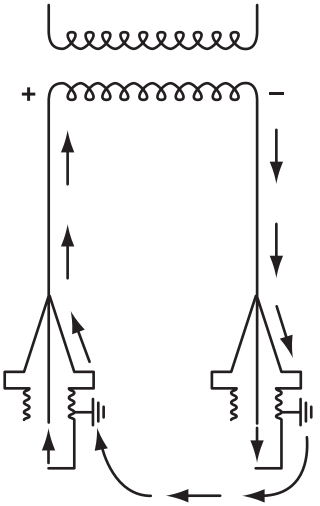


Figure 4–19 Current flow in a waste spark EI system.

of the compression stroke (this cylinder's spark is referred to as the *event spark*) and the other cylinder will be near the end of the exhaust stroke (this cylinder's spark is referred to as the *waste spark*). Then, 360° of crankshaft rotation later, the strokes will be reversed between these two cylinders; but each time the coil fires, one of the cylinders will always use the spark to ignite an air/fuel charge. Coil polarity stays the same regardless of which cylinder is completing the compression stroke. While most of these systems use two secondary wires to connect a given coil to the two plugs that it fires, some applications mount the coil directly on top of one of the plugs and then connect the coil to the mating plug with a single secondary wire, thus eliminating half of the secondary wires.

The other EI system uses one ignition coil for each cylinder. This system is actually simpler in concept than the waste spark system. Each coil fires only one spark plug from the center electrode to the side electrode (Figure 4–20). Then a direct path is provided for the spark back to the positive end of the secondary winding. These EI systems, generally referred to as *coil-on-plug* (COP), have the ignition coil situated physically on top of the spark plug that it fires. Some applications mount the coil near the spark plug rather than on the plug (due to the close proximity of the exhaust manifold) and then use a short secondary spark plug wire to connect them. This is usually referred to as *coil-near-plug* (CNP). Either design may also be referred to as *coil-per-plug* (CPP). An advantage of the COP design is that, because the coil is mounted directly on the plug and no secondary wires are used, it reduces the potential for secondary wiring to induce voltages in other nearby circuits.

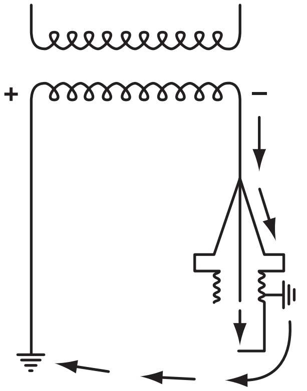


Figure 4–20 Current flow in a COP EI system.

It should also be noted that many COP ignition coils contain their own driver (transistor). These simply receive a digital control signal from the PCM to the base leg of the driver.

Primary Ignition System Levels of Information

The information that is provided to the ignition module and/or PCM can be broken down into three distinct levels of information. Understanding these various levels of information will allow you to apply these concepts to any system that might be encountered so as to enhance your understanding of these systems.

The first level of information that might be provided to the ignition module and/or PCM is simply that "a *pair* of cylinders' pistons are approaching TDC." No further information is provided. Systems that would require only this level of information include DI systems in terms of spark management, and feedback-carbureted systems and TBI systems in terms of fuel management. In these systems, it is not necessary for the PCM to know which cylinder is the number one cylinder. (In a DI system, it is the distributor's responsibility, not the PCM's, to deliver the spark, once created, to the proper cylinder's spark plug.)

The second level of information that might be provided to the ignition module and/or PCM is "*which pair* of cylinders' pistons are approaching TDC." This information is needed to correctly choose which coil to fire in a waste spark system. (The PCM does not need to have any additional information because if the correct waste spark coil is fired, both cylinders' spark plugs will fire and an air/fuel charge will be ignited, regardless of which cylinder was on the compression stroke.)

The third level of information that might be provided to the ignition module and/or PCM is "*which cylinder* of the piston pair approaching TDC is on the compression stroke." This information is needed to correctly choose which coil to fire in a COP system. It is also needed for any sequentially injected PFI system.

Ultimately, the information that is provided is never more than what is needed for proper system operation, and, therefore, the level of information provided is always determined by the systems that are used in a given application.

Primary Ignition System Sensors

In a multiple coil system, information of the first level will originate at a **crankshaft position (CKP) sensor.** (Few exceptions to this exist, but one exception was a Mitsubishi multiple coil ignition system produced in the 1990s that used dual optical camshaft sensors only and no crankshaft sensor.) The reason that most multiple coil systems take the first level of information from the crankshaft is that the timing of this signal can be designed fixed without having to allow for adjustments to compensate for timing chain stretch. This will be the primary tach reference signal. If this signal is lost, no spark plug will fire, no fuel injector will be pulsed, and the fuel pump relay will be de-energized, resulting in an immediate stall of the engine and no restart. Figure 4–21 shows a Hall effect CKP sensor that provides the first level of information only—all vanes are the same size and are equally spaced. When the PCM sees a leading edge of a vane, it only knows that *a pair* of pistons are approaching TDC.

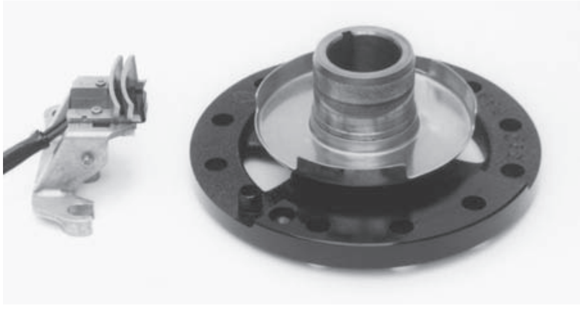


Figure 4–21 Hall effect CKP sensor and harmonic balancer with three vanes and three windows, all equally sized and equally spaced.

Information of the second level may or may not originate at the CKP sensor. That is, on applications where this level of information is needed, the CKP sensor can be modified to inform the ignition module and/or PCM of this level of information. Figure 4–22 shows a magnetic CKP sensor that provides both the first and second levels of information due to an extra offset notch in the reluctor wheel that is not evenly spaced with the others. This allows the PCM to know the exact position of the crankshaft, thus indicating *which pair* of pistons are approaching TDC.

Information of the third level cannot be obtained from a CKP sensor. No matter how it may be modified, a CKP sensor will always "look the same" on both revolutions that, together, make one full cycle on a four-cycle engine. Rephrased, the PCM will not be able to tell the compression stroke from the exhaust stroke if it only uses a CKP sensor. However, this information can be provided by a **camshaft position (CMP) sensor** due to the fact that a camshaft will only make one revolution to complete all four cycles on a four-cycle engine. Therefore, if the application uses either SFI or a COP ignition system, it will require a CMP signal.

When a CMP sensor is present, the second level of information may come from the CMP sensor simultaneously with the third level of information, leaving only the first level of information to be derived from the CKP sensor. However, if it is used with a waste spark ignition system, the ignition module and/or PCM will not be able to fire a coil until it has substantiated this second level of information. Potentially, it could take up to one full rotation of the camshaft to derive this level of information, which translates to two full rotations of the crankshaft. If the CKP sensor is modified to inform the ignition module and/or PCM of the second level of information, the result is a potential to begin firing the ignition coils earlier during engine start. (A PCM may pulse SFI injectors prior to seeing the third level of information if it is programmed to deliver a primer pulse during

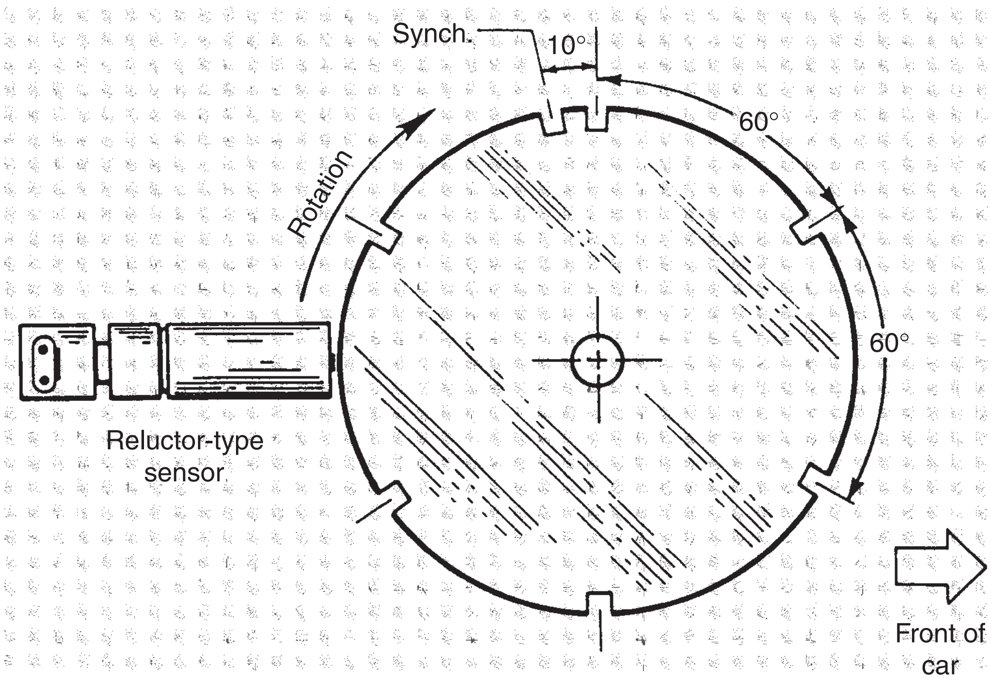


Figure 4–22 Magnetic CKP sensor with an offset notch for identifying the second level of information.

engine crank. Therefore, starting will not be delayed by reason of the fuel injection system.)

A few applications now create a CMP signal without the use of a physical camshaft sensor. Both the first and second levels of information must be derived from the CKP sensor. On a waste spark application, this can be achieved by commanding a primer pulse at the fuel injectors and then using the CKP information to fire the correct waste spark coil. As the coil is fired, smarter electronics measure the voltage drop across each of the two spark plugs. The plug with the larger voltage drop is the one that is firing on the cylinder that is on the compression stroke. (Remember that increasing the cylinder pressure increases the electrical resistance across a spark plug gap, therefore requiring a higher voltage to jump the gap.) As a result, the PCM is able to artificially create a CMP signal and will then begin to pulse the injectors in sequence. A few COP applications create the CMP signal artificially by initially firing two ignition coils on opposite (companion) cylinders after the CKP information is received (Saab, for example). The voltage drop across each plug is measured, the CMP signal is created, and then the PCM begins proper sequencing of the fuel injectors and ignition coils.

With DI systems, a distributor may be designed to provide only the first level of information or all three levels of information, depending upon the type of fuel management system that is used with it.

Regardless of the system design and because of the importance of the primary waveform signals, a **grounded shield** is used with many systems to protect the primary ignition circuitry from the potential induction of a voltage signal caused by a nearby circuit. This grounded shield consists of a bare wire that is grounded at one end only (to ensure that it will not flow any current) and runs the length of the primary circuitry. The bare wire and the primary circuit wires are then wrapped

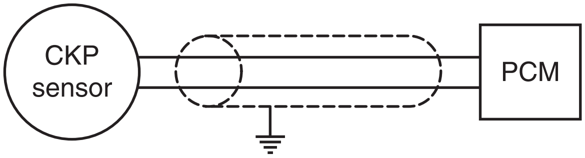


Figure 4–23 Example of a grounded shield.

with aluminum foil. Figure 4–23 shows a typical electrical schematic that identifies a grounded shield. When repairing a primary circuit wire, it is important to avoid compromising the integrity of the grounded shield. A grounded shield may also be found with other circuits/systems, such as around the wiring from a wheel speed sensor in an antilock brake system.

Ignition Module and PCM Overview

Traditionally, many systems have used an ignition module that is separate from the PCM (Figure 4–24). In this design, the ignition module will receive the tach reference signal. This signal may originate at either a CKP sensor or at a distributor pick-up and may originate with either a magnetic sensor, a Hall effect sensor, or an optical sensor (see Chapter 3). The ignition module will use this signal to fire the ignition coil(s) at base timing when necessary (typically during engine crank); it will also pass a digitized version of this signal on to the PCM. (The ignition module will digitize the analog AC voltage pulse that it receives from a magnetic sensor.) The PCM then uses this tach reference signal, along with information from its other sensors, to create a modified digital timing command signal that is sent back to the ignition module. This modified timing command signal is actually advanced in time. The PCM is able to advance this signal because it uses the frequency of the tach reference signal to calculate engine speed—not only revolutions per minute (RPM) but also how many degrees of crankshaft rotation are occurring per millisecond.

If the ignition module is firing the ignition coil(s) from the tach reference signal, the engine is said to be operating at base timing. If the ignition module is firing the ignition coil(s) from the PCM's timing command signal, the engine is said to be operating at computed timing. The strategy used for switching a system between base timing and computed timing will vary among manufacturers.

The tach reference signal is also used by the PCM for injector pulsing and is required if the PCM is to energize the fuel pump relay past the initial two-second pulse that occurs when the PCM is initially powered up. In a combination EI/SFI system, this tach reference signal will be the one originating at the CKP sensor. The CMP sensor signal is

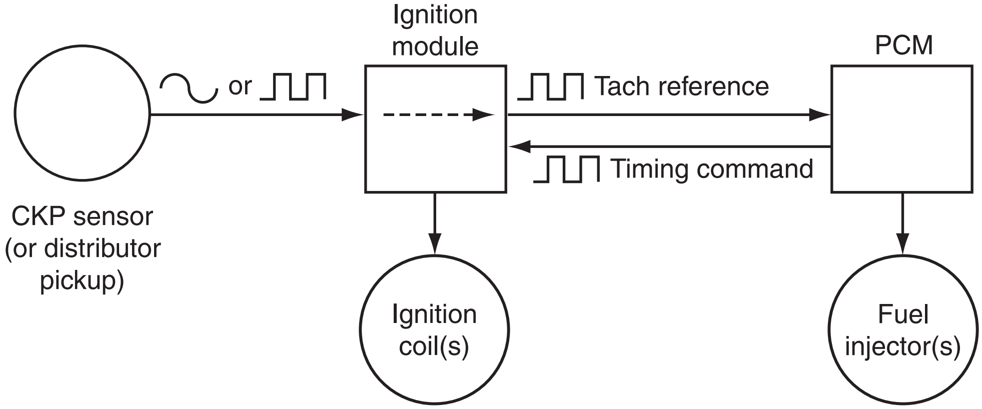


Figure 4–24 System with an ignition module that is separate from the PCM.

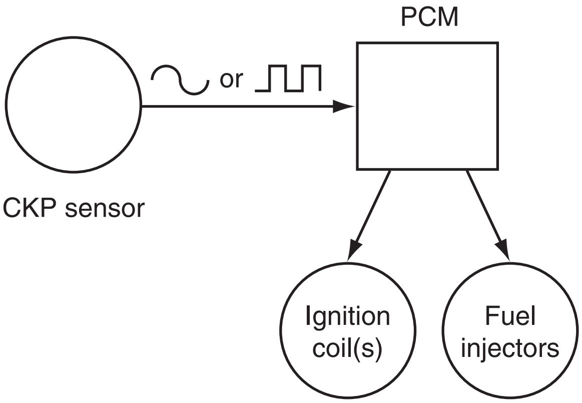


Figure 4–25 System with the ignition module equivalent located internally within the PCM.

only used by the PCM to determine which injector/ignition coil should be pulsed/fired next.

In another system design, the ignition module is no longer separate from the PCM, but its equivalent is placed inside the PCM (Figure 4–25). In this design, the PCM receives the CKP and CMP signals directly from the sensors and then uses the CKP signal to pulse the injectors and fire the ignition coil(s) directly. Again, the CMP signal is used for injector and ignition coil sequencing. Chrysler Corporation originated this design back in the 1970s, but several other manufacturers have now adopted it. At least one manufacturer states that this design was chosen because it enhances the effectiveness of the antitheft disabling system on the vehicle. A variation of this design uses a PCM to control external switching transistors located in an “igniter” or even in the ignition coils. The PCM still receives the CKP and CMP signals directly from the sensors, but it does not have to carry the higher current flow that the ignition coils draw.

Diagnosing for the Presence of CKP and CMP Sensor Signals

When chasing a “no start” condition on an EI/SFI application, check for the presence of an injector pulse and a primary ignition coil pulse—if either one exists, the PCM is receiving a tach reference pulse from the ignition module, which, in turn, is receiving it from the CKP sensor or distributor pick-up and is passing it on to the PCM. If neither one exists, the CKP sensor should be checked, followed by testing of the continuity of the signal’s path to the ignition module, through the ignition module, and from the ignition module to the PCM.

In a system with waste spark EI and SFI, if the CKP sensor provides both the first and second levels of information to the PCM, and the PCM is receiving the CKP signal but is not receiving the CMP signal, it will likely guess at the correct injector sequence according to its internal programming and the correct ignition coil will also be fired. Some PCMs are even programmed to guess at the correct ignition coil firing sequence during engine crank if the second level of information is lost. But if the first level of information is lost, the engine stalls immediately and will not restart.

EMISSION-CONTROL SYSTEMS

Precise control of the air/fuel ratio and spark timing combined with keeping the engine coolant temperature between 93°C (200°F) to 104°C (220°F) and even controlling combustion temperature dramatically reduce exhaust emissions. However, even these measures do not totally eliminate vehicle emissions. Therefore, other control systems are added to the vehicle with the ultimate goal of further reducing emissions.

Catalytic Converters

Catalytic Converter Overview. The catalytic converter is the single most effective device for controlling exhaust emissions. Located in the exhaust system, the **catalyst** agents cause low-temperature oxidation of HC and CO (oxidizing HC into H_2O and CO_2, and oxidizing CO into some additional CO_2) and reduction of NO_x (into N_2 and O_2). Placing the converter downstream in the exhaust system allows the exhaust gas temperature to drop significantly before the gas enters the converter, thus preventing the production of more NO_x in the oxidation process.

The catalysts that are used most often are **platinum** and **palladium** for oxidation of HC and CO and **rhodium** for reduction of NO_x. The catalytic materials are applied over a porous material, usually aluminum oxide in pellet form or aluminum oxide in a honeycomb structure. Aluminum oxide's porosity provides a tremendous amount of surface area on which the catalyst material can be accessed to allow maximum exposure of the catalyst to the gasses.

There have been three different types of catalytic converters used on automobiles: (1) a single-bed, two-way converter that was introduced on cars in 1974; (2) a single-bed, three-way converter that was introduced on cars in the late 1970s; and (3) a dual-bed, three-way converter that is the more common design since the early to mid-1980s.

A single-bed catalytic converter has all the catalytic materials in one chamber (Figure 4–26). A single-bed, two-way converter oxidizes HC and CO; a single-bed, three-way converter oxidizes HC and CO and reduces NO_x.

A dual-bed, three-way catalytic converter has a reducing chamber for breaking down NO_x and an oxidizing chamber for oxidizing HC and CO. The exhaust passes through the NO_x reduction chamber first, then through the HC/CO oxidation bed (Figure 4–27). On some vehicles additional oxygen is introduced into the oxidation chamber via a secondary air injection system to increase the efficiency of this chamber by ensuring that it is kept up to the ideal operating temperature.

HC/CO Oxidation Bed Operation. The oxidation bed of a catalytic converter uses platinum and palladium to oxidize the HC molecules into water and carbon dioxide and the CO molecules into additional carbon dioxide. To oxidize HC and CO, a lean air/fuel mixture is needed to yield leftover oxygen. During closed loop operation (when the oxygen sensor is cross-counting), the oxidization converter is designed to store oxygen from the lean O_2 sensor pulse (when no CO and little HC are produced) in its extremely porous surfaces and then give up the stored oxygen during the rich O_2 sensor pulse (when CO and the majority of the HC are produced). Thus, the oxygen from the lean exhaust pulses can mix with

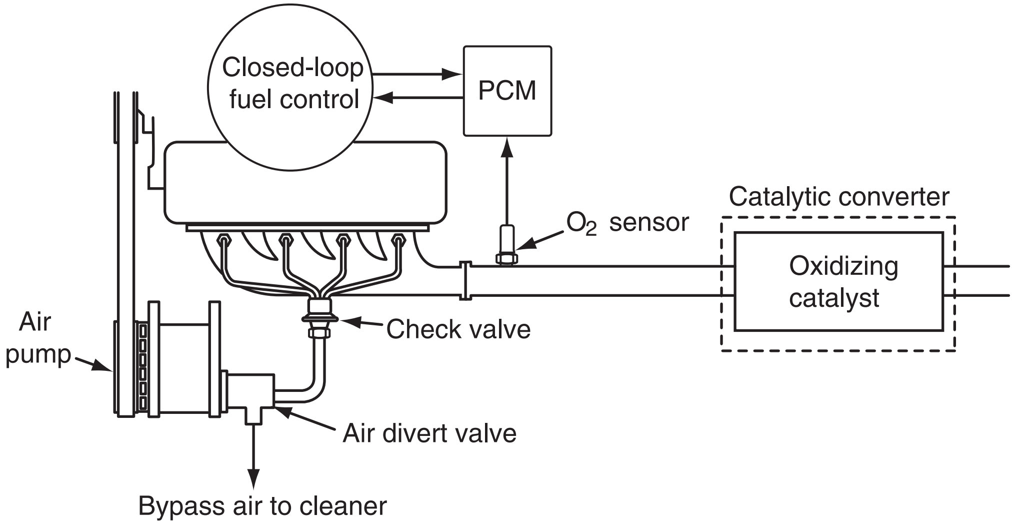


Figure 4–26 Single-bed, three-way catalytic converter.

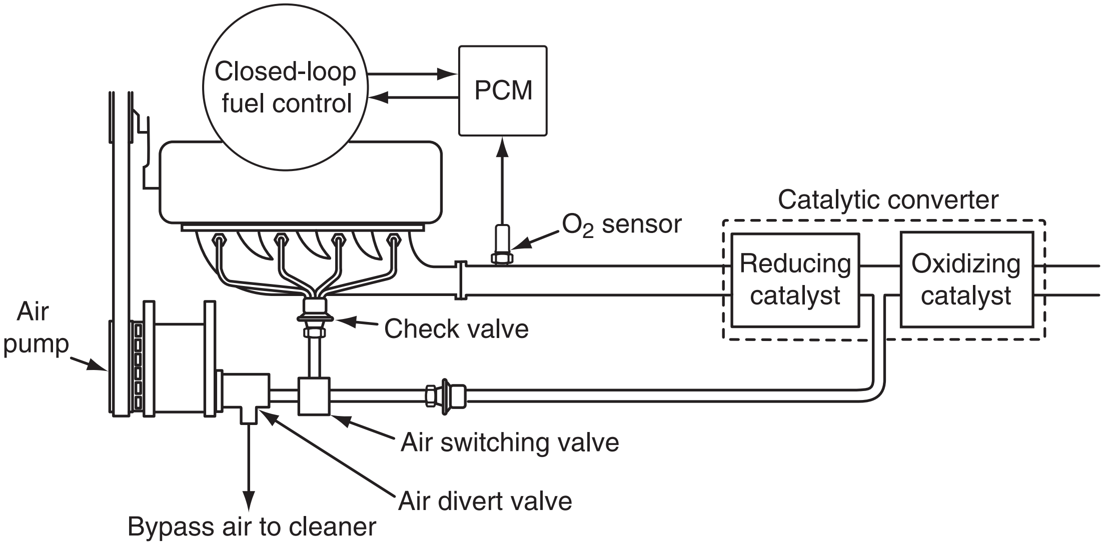


Figure 4–27 Dual-bed, three-way catalytic converter.

the HC and CO, allowing all three substances to touch the catalyst metals simultaneously and thus allowing the oxidation of the HC and CO to take place.

NO_x Reduction Bed Operation. The reduction bed of a catalytic converter uses rhodium to break down the NO_x molecules (NO and NO_2, collectively known as NO_x) into nitrogen and oxygen. However, it can only do so if there is a small amount of CO also present simultaneously in the engine's exhaust. The CO molecule is an oxygen-deficient molecule. Therefore, to reduce NO_x, a rich air/fuel ratio is required, resulting in the production of a small amount of CO. When mixed with the NO_x, the CO molecules promote the breakup of the NO_x molecules by attracting an oxygen atom from the NO_x molecule, resulting in the breakup of the entire molecule. Simultaneously, the CO molecule is converted to a CO_2 molecule. With the only oxygen atom extracted from an NO molecule, nitrogen atoms are left to form nitrogen molecules. With one of the oxygen atoms extracted from an NO_2 molecule, some free oxygen atoms are also left to form some additional oxygen molecules as well.

Initially, NO_x reduction converters only reduced NO_x during the rich O_2 sensor pulse, when the air/fuel mixture was rich enough to produce CO, and never during the lean O_2 sensor pulse, when the majority of the NO_x is normally produced in the combustion chamber. (While the peak combustion temperature is reached slightly to the rich side of stoichiometric, most of the oxygen has been consumed when the air/fuel mixture is rich by the time the peak combustion temperature is reached. Therefore, when the engine is running correctly, most NO_x is produced when the air/fuel mixture is slightly lean due to the leftover oxygen that was not consumed during combustion.) This meant that reduction converters were less than 50 percent efficient in reducing the NO_x produced in the combustion chamber. However, recent catalytic converter technological updates have now given the NO_x reduction converter the ability to store CO from the rich O_2 sensor pulse and give it off during the lean O_2 sensor pulse when the majority of the NO_x is making its way through the exhaust.

Catalytic Converter Backpressure Tests. Most manufacturers have experienced some problems with catalytic converters becoming restricted and have developed backpressure tests to test for this condition. Depending on the severity of the restriction, the symptoms vary from slight loss of power after several minutes of driving to the engine not starting in the first place.

Always begin by tapping on the converter with a rubber mallet, listening for anything loose inside. One quick test that might be indicative of excessive exhaust backpressure is to measure intake manifold vacuum at idle and then again at 2500 RPM. As the RPM is increased, a loss of more than about 2″ Hg of vacuum is indicative of excessive exhaust backpressure. (As vacuum is the inverse of pressure, this amounts to an increase in pressure of about 1 PSI.)

To test for excessive exhaust backpressure directly, tap into the exhaust ahead of the catalytic converter with a pressure gauge that can read from 0 to 10 PSI. Then, with the engine running at 2500 RPM in the service bay (no load), backpressure should generally not exceed about 1½ PSI. Backpressure tests can be performed on all converters, regardless of whether they are oxidation converters or reduction converters and whether they are OBD II or pre-OBD II converters.

HC-to-CO_2 Conversion Test. One chemical test that has been developed can test an oxidation converter's efficiency by testing for the converter's ability to convert hydrocarbons to carbon dioxide. However, this test should only be used on vehicles manufactured prior to OBD II and only on oxidation converters. Remember, NO_x reduction converters were not that efficient prior to OBD II. And OBD II PCMs test their own converters with much more accuracy than chemical tests are capable of, so this test should also be restricted to pre-OBD II converters.

To perform this test, begin by getting the converter up to normal operating temperature. This involves running the engine until the upper radiator hose is hot and pressurized, then running it for an additional two minutes at 2000 RPM. (An easier method is to take the vehicle on a short road test.) Once this is accomplished, insert a concentration type gas analyzer's probe into the tailpipe. (See "Gas Analyzers" in Chapter 7.) Turn the engine off, and then disable the secondary ignition system without disabling the fuel injectors. Then crank the engine for 10 seconds. Follow this by using the gas analyzer to measure the HC and CO_2 concentrations exiting the tailpipe for the next 30 or 40 seconds. HC levels that remain below about 500 PPM or CO_2 levels that go above 12 percent indicate that the converter is working quite efficiently. Because we cannot absolutely control the quantity of fuel injected into the engine, an "either/or" pass specification is allowed. With a smaller quantity of fuel, the converter passes if it can hold the hydrocarbons below 500 PPM, even though carbon dioxide does not go very high. With a greater quantity of fuel, the converter passes if the carbon dioxide rises above 12 percent, even though it is unable to hold hydrocarbons low. Use this test simply to give you some indication as to the oxidation bed's efficiency.

Other Emission-Control Systems

Other emission-control systems currently used on most vehicles and those that can be included as part of the computerized engine control system, or added to it, are discussed in this section.

Positive Crankcase Ventilation. The positive crankcase ventilation (PCV) system is designed to recirculate blow-by gasses from the crankcase through the intake manifold and into the cylinders to burn them in the combustion chamber. Therefore, the PCV system is designed to reduce HC emissions that were once vented to the atmosphere through a road draft tube.

First introduced on California vehicles in the 1961 model year and in the other 49 states in the 1963 model year as an *open PCV system*, this system drew ambient air through the crankcase to pick up any blow-by gasses. In 1968, this system was modified into a *closed PCV system* that draws filtered air in from the air cleaner, then through the crankcase to pick up any blow-by gasses (Figure 4–28). The combination of fresh air and blow-by gasses is then drawn through a metering device, either a PCV valve or a metering orifice, and into the intake manifold, thus allowing

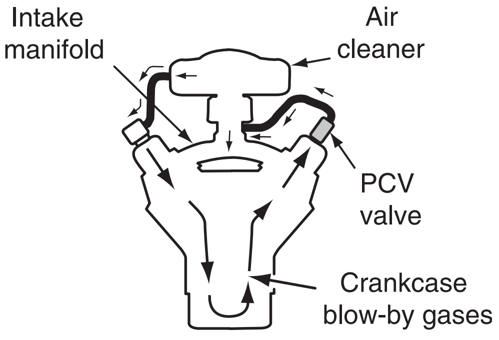


Figure 4–28 PCV system basic operation.

the crankcase hydrocarbons to be burned in the cylinders. This combination of fresh air and blow-by gasses tends to lean out the air/fuel mixture, so the PCV system is considered to be a calibrated vacuum leak.

If for any reason the crankcase vapors exceed the PCV system's capacity, either due to a PCV system fault or due to excessive blow-by gasses getting past the piston rings (which would indicate worn rings), vapors are routed into the intake air stream through the intended crankcase inlet and will still be drawn through the throttle body into the intake manifold (not true of the early *open PCV system*). However, as a result, the blow-by gasses are no longer purged efficiently from the crankcase and there now exists a greater tendency to form sludge. An incorrect PCV valve can cause as many problems as a worn or plugged one. Therefore, when diagnosing PCV system problems, always begin by replacing the PCV valve with one of the correct part number and verify proper manifold vacuum is made available to the valve. This is one of the few times that parts replacement is recommended in lieu of initial diagnosis: It would not be wise to spend $100 of diagnostic time due to a worn or incorrect $5 part.

Thermostatic Air Cleaner. The thermostatic air cleaner (TAC) system uses a heat stove wrapped around an exhaust manifold to heat intake air before it enters the air cleaner during engine warm-up (Figure 4–29). It is used on systems that have both air and fuel moving through the intake manifold. It is used to reduce CO and HC emissions by reducing the tendency of the fuel to condense against the cold intake manifold walls and puddle on the floor of the intake manifold. (Condensed fuel would likely vaporize during a deceleration condition when it is not needed, due to the ultra low pressure/high vacuum, thereby causing the air/fuel ratio to go extremely rich.) The TAC system is usually not controlled by the PCM and is not used with most PFI systems.

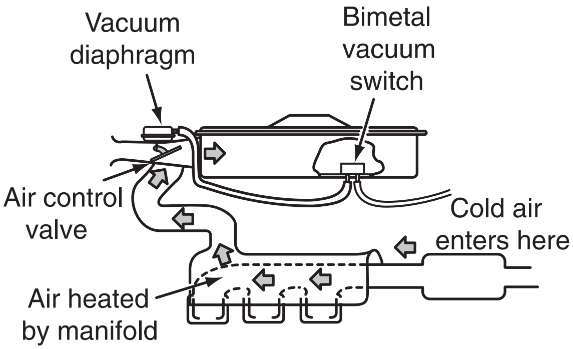


Figure 4–29 A typical TAC design.

Early Fuel Evaporation. Early fuel evaporation (EFE) systems are also designed to reduce the tendency of the fuel to puddle in a cold intake manifold during engine warm-up to reduce CO and HC. The EFE system comes in two forms: A heat riser valve (Figure 4–30) is used on most V-type

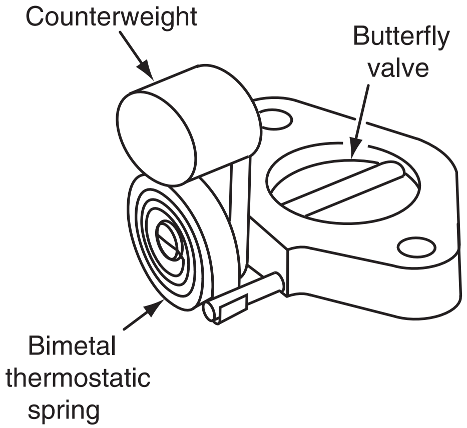


Figure 4–30 A typical mechanical heat riser valve used in an exhaust heat EFE system.

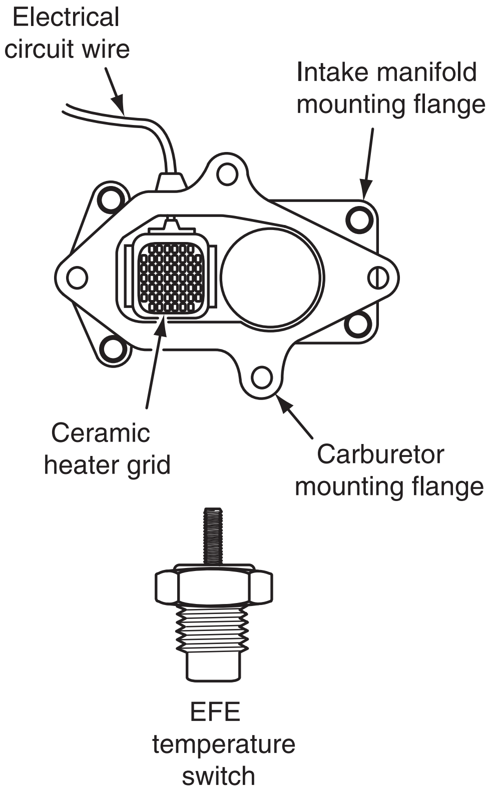


Figure 4–31 A typical EFE heat grid with its controlling temperature switch.

engines to direct exhaust gas from one exhaust manifold through an exhaust passage in the intake manifold to the exhaust manifold on the other side of the engine, and an electric heat grid (Figure 4–31) may be built into the base gasket of the carburetor or throttle body. The heat riser system may be controlled by the PCM through a vacuum solenoid and a vacuum diaphragm that operates the heat riser valve. The EFE grid may be under control of the PCM via a relay. These systems are not generally used on a port fuel injected engine.

Air Injection Reaction System. An air injection reaction (AIR) system, also commonly known as a *secondary air injection system*, uses an air pump to pump air into the exhaust manifold to help oxidize CO and HC coming out of the combustion chamber. Whereas most systems initially used a belt-driven air pump, many newer systems use an electrically driven pump (although this system is no longer used as extensively on the modern automobile as it once was). Check valves (Figure 4–32) are used to prevent hot exhaust gasses from reaching the rest of the AIR system while still allowing the air pump to push air into the exhaust system. Most systems also have a provision to dump the air to the atmosphere (or turn off the electrically driven pump) when rich air/fuel conditions are present, to prevent backfire out of the exhaust system or overheating of the catalytic converters.

Some versions use exhaust pressure pulses to pump air instead of an air pump; these are known as *pulse AIR* (PAIR) systems. An exhaust system develops positive pressure pulses (pressure slightly above atmospheric pressure) as each puff of exhaust exits the cylinders, as well as negative pressure pulses (pressure slightly below atmospheric pressure) between the positive pressure pulses. The negative pressure pulses are developed due to the fact that the exhaust is flowing (moving air tends to create a low-pressure area). In a PAIR system, a check valve is used to allow the negative pressure pulses to bring air into the exhaust system while blocking the positive pressure pulses from reaching the rest of the AIR system. Typically, a PAIR system cannot flow as much volume as those systems that use an air pump and they are, therefore, generally used on engines of smaller displacement.

When used with a closed-loop fuel control system, the only time that air is directed to the exhaust manifold is during engine warm-up to help pre-warm the oxygen sensor(s) and the catalytic converter(s). If this system is used with a dual-bed catalytic converter (or multiple converters), air is switched to a downstream exhaust port located after the NO_x reduction bed but before the CO/HC oxidation bed during closed-loop operation (Figures 4–27 and 4–32). This is because directing the additional air ahead of either the oxygen sensor or the NO_x reduction converter would interfere with the proper function of either of these devices once the engine is warmed up

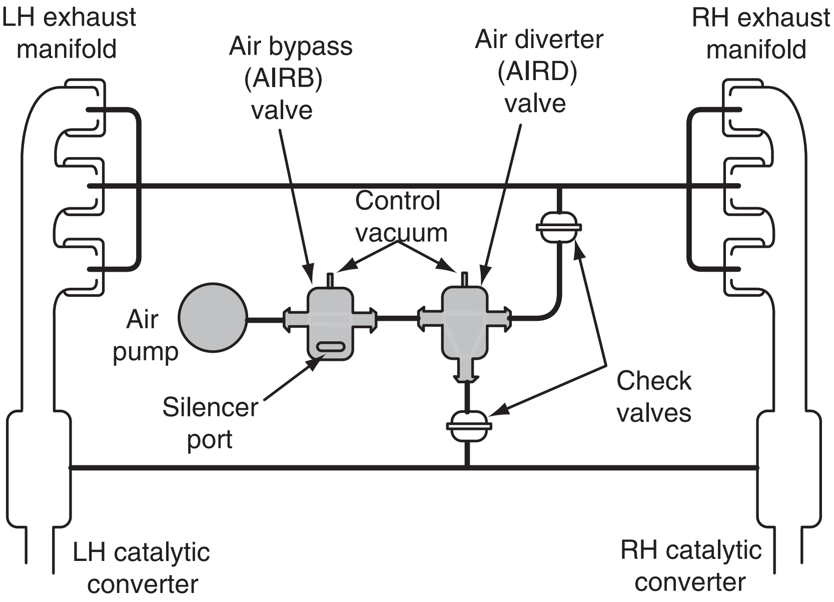


Figure 4–32 A typical secondary air injection system.

and in closed loop. The air is then dumped to the atmosphere during rich engine operating conditions such as wide-open throttle (WOT), deceleration, or extremely cold initial engine starts. This system is typically under the control of the engine computer.

Evaporative and Canister Purge Systems. These systems are designed to prevent the release of HC emissions to the atmosphere through evaporation. The fuel tank (and carburetor float bowl, if applicable) is vented to a charcoal canister (Figure 4–33). Then, when the engine

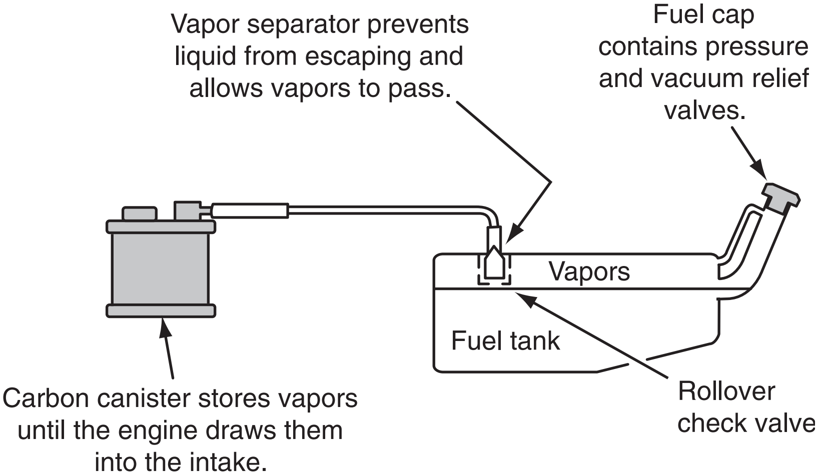

Vapor separator prevents liquid from escaping and allows vapors to pass.
Fuel cap contains pressure and vacuum relief valves.
Vapors
Fuel tank
Rollover check valve
Carbon canister stores vapors until the engine draws them into the intake.

Figure 4–33 In a typical evaporative emission system, the fuel tank is vented to a charcoal canister.

Diagnostic & Service Tip

Charcoal canister saturation can often be the result of fuel tank overfilling. Slowly filling the tank right to the top of the filler neck causes the anti-overfill chamber in the tank to fill and thus leaves no room for fuel expansion. When the fuel does expand, it is pushed up and into the charcoal canister. Canister purging then dumps so many hydrocarbons into the intake manifold that the system may not be able to compensate, even in closed loop. Many driveability problems can be linked to charcoal canister problems; do not overlook that in diagnostic procedures.

is running, manifold vacuum purges the HC emissions from the canister to the intake manifold for combustion in the cylinders. On early systems, the manifold vacuum signal used to purge the canister was controlled by a ported vacuum signal to a purge demand valve. On newer systems, purging may be under the control of the PCM, either by controlling a vacuum solenoid in conjunction with a purge demand valve or by controlling the purging directly with a purge solenoid. On-board diagnostic (OBD) II applications (described in Chapter 8) use an evaporative system that has become increasingly complex on late-model vehicles due to the added ability of the engine computer to check the system for leaks to minimize the escape of HC emissions to the atmosphere through a missing gas cap or other fuel tank leak.

Exhaust Gas Recirculation. Exhaust gas recirculation (EGR) systems use an EGR valve (Figure 4–34) to allow recirculation of exhaust gasses back into the intake manifold to replace incoming air and oxygen with inert exhaust gas. This reduces the amount of ambient air getting into the cylinder. With a carburetor, an automatic reduction in fuel delivery occurs in response to the reduction of ambient air reaching the cylinders. With a computerized fuel management system, the PCM reduces the amount of fuel to maintain the proper air/fuel ratio whenever the EGR valve is opened. Ultimately, with reduced oxygen and fuel reaching the cylinders, combustion chamber temperatures are lowered, which reduces the amount of NO_x that is produced during combustion.

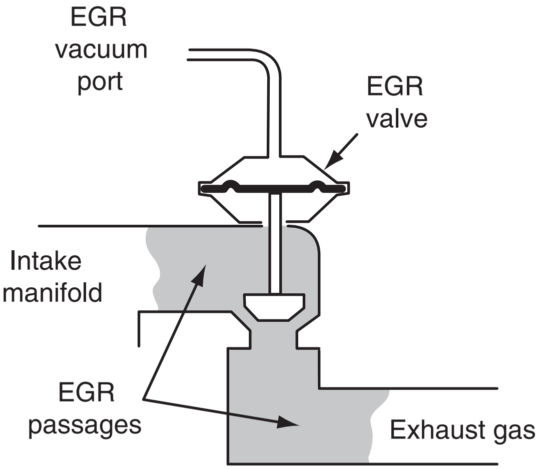


Figure 4–34 Opening of an EGR valve allows exhaust gasses to flow into the intake manifold, displacing incoming ambient air and oxygen.

Use of an EGR system allows the engineer to design an engine with a higher compression ratio or increased VE while still keeping NO_x production at a minimum. An added benefit is that a more aggressive spark advance program can be programmed into the middle RPM and load ranges, resulting in improved engine performance and fuel economy, while continuing to control spark knock. As a result, an EGR valve that is physically stuck closed can be responsible for a spark knock complaint under mid-range light to moderate acceleration.

An EGR valve may be a vacuum-operated valve which, in turn, controls a passage between the intake manifold and the exhaust manifold. It may be under the control of a ported vacuum signal or under the control of an engine computer via vacuum control and/or vacuum vent solenoids. The engine computer may **modulate** these solenoids or it may operate a solenoid on a duty cycle to control the percentage of time that a solenoid is applying vacuum versus the time that it is venting vacuum. Other EGR valves are electrically operated valves that control the exhaust gasses directly and without the use of vacuum.

EGR valves are not opened at idle so as not to detract from the idle quality of the engine, nor are they opened at WOT so as not to interfere with all-out engine performance. On some older systems (beginning in 1980), the PCM monitors the EGR valve's position, resulting in a feedback type of control of the EGR system. On OBD II vehicles, the PCM is required to monitor the EGR system for both flow rate and leakage, although several different methods are used (see Chapter 8).

VARIABLE VALVE TIMING

In an effort to extract more performance from smaller engines while providing good driveability throughout the operating range of the engine and keeping vehicle emissions in check, manufacturers have begun using variable valve timing. Such a system can vary the relationship of the valve opening and closing to the crankshaft's position.

Functional Concept

The PCM is able to vary valve timing by rotating a camshaft in its relationship to the crankshaft. This is commonly done by using a hydraulic control signal (under the control of a PCM-controlled solenoid-operated valve) to change the position of the camshaft gear on the camshaft, using a helical spline. This rotates the camshaft in its relationship to the cam gear, thus changing the camshaft's relationship to the crankshaft as well. On some engines, hydraulic pressure is applied within a hollow cam gear assembly and is used to rotate a mechanism that is attached to the end of the camshaft.

Variable valve timing can be used to control NO_x exhaust emissions by retaining some exhaust gas within the cylinder. However, although an engine with variable valve timing is less likely to have an EGR system, some high-compression engines with variable valve timing continue to use an EGR system as well to control NO_x emissions. The use of variable valve timing also allows a higher compression engine to use fuel of a lower octane (as opposed to an engine that cannot vary its valve timing) without creating a detonation problem. Ultimately, this system is designed to increase the high-performance capability of the engine while maintaining good driveability and emissions.

42-V SYSTEMS

Introduced in vehicles in the United States in the 2004 model year, 42-V systems will be used increasingly over the next several years. The pressing need to convert to a higher-voltage system has been driving this evolution for several years now, for the same reasons that 14-V systems replaced 7-V systems decades ago.

The Need for More Power

You may recall that total power, or wattage, is equal to voltage multiplied by amperage. As engineers have continued to add many electrical and electronic systems to the automobile over the past several decades, more and more total power has been required to control and operate these systems. Because power is not free, the manufacturer's reaction to an ever-increasing power requirement traditionally has been to build larger alternators capable of producing more and more amperage. It has been obvious for some time now that eventually we would have to increase the vehicle's operating voltage as a method of meeting these power demands.

Today's vehicles may use electrical power for any combination of the following systems:

- computerized engine controls
- electronically controlled automatic transmissions
- electronically controlled interior and exterior lighting systems

- electronically controlled gauge systems
- electronically controlled body systems, including heated front and rear seats as well as seat cooling systems
- electronic antilock braking and traction control systems
- electronically controlled stability control systems
- electronic active suspensions systems including both load leveling and shock dampening systems
- electronic passive restraint systems, including frontal air bags, side air bags, head air bags, knee air bags, and seat belt pre-tensioners
- variable assist power steering systems
- electromagnetic steering systems
- electronically controlled cooling fans
- heated rear window defrosters
- heated outside mirrors
- heated windshield de-icing systems
- heated windshield wipers
- electrochromic inside and outside rear view mirror systems
- remote-controlled electrically operated exterior door systems
- anti-theft systems including both warning and disabling systems
- smart key systems
- entertainment systems, including DVD players with relatively high-wattage sound systems
- integrated voice recognition, navigational, and Bluetooth wireless control systems

42 V as a World Standard

When engineers were looking at what voltage to use as a standard, one of the considerations was the fact that voltage above 50 V can cause a fatal shock. Therefore, the 42-V standard was adopted as a worldwide standard. It is essentially three 12.6-V batteries in series, producing a total of 37.8 V, plus charging system voltage, for a total of 42 V. This triples the kilowatt capability of the electrical system without becoming dangerous to a technician. (Today's hybrids use dangerously high voltage levels, from 144 to 650 V, but the use of 42-V systems creates little potential for a fatal shock.) Also, do not confuse a hybrid voltage (dual voltage) system with a hybrid drive system, although both systems may use regenerative braking.

42-V System Designs

The automotive world is not likely to transform the entire automobile into a 42-V system overnight. The changes will occur progressively because, as it happens, everything from light bulbs and other electrical parts to battery chargers and other service equipment will have to be upgraded simultaneously. Therefore, today's 42-V systems will likely keep a 14-V subsystem intact for some years. Retaining a separate 12.6-V battery that would be charged through a pulse-width modulated signal from the 42-V system might be used to do this, or the 42-V system might use pulse-width modulation to power a 14-V subsystem without the additional battery. The starter motor can be designed as a 12.6-V starter or as a 37.8-Vcombination starter/generator. The advantages of the 37.8-V combination starter/generator are that reduction gearing is not needed and that regenerative braking can be incorporated. Regardless, these vehicles will continue to use many 14-V loads for some time to come.

Advantages of a 42-V System

With the large increase in voltage, many heavy-duty components that are traditionally belt-driven will likely be driven by a 42-V motor, including AC compressors, water pumps, and power steering pumps (in those systems that retain a hydraulic power steering system). Also, with a threefold increase in voltage, the amperage can be cut back equally and still maintain a given wattage; therefore, smaller-diameter wiring can be used, thus cutting back on vehicle weight. Engineers are more likely to add 120-V power points to power common devices such as televisions, DVD players, and laptop computers, because only a 3× step-up transformer is required.

42-V System Concerns

There are many concerns associated with 42-V system designs, including service equipment, service procedures, and safety issues. Battery chargers and other service and diagnostic equipment must be redesigned. Back-probing of a connector as a diagnostic procedure will no longer be an option. If the wiring's insulation is compromised in a 42-V system, a greatly increased potential for corrosion (even with the system at rest) as well as a greater potential for arcing will exist. In addition, 42-V arcs are more than 50 times hotter than 14-V arcs. The best advice, as these systems are introduced, is to pay particular attention to manufacturer-recommended diagnostic and maintenance procedures.

SUMMARY

This chapter has dealt with many concepts related to the design and operation of modern fuel injection, spark management, and emission-control systems. We have also discussed some basic aspects of variable valve timing systems. We concluded our chapter with a discussion on the need for more electrical power on the modern automobile and the reasons manufacturers have begun to add 42-V systems to the automobile. The intent of this chapter is to create a foundation upon which the reader will build as he/she continues to progress through the remainder of this textbook. We have covered several aspects of each of these systems that are common to most of the vehicles produced today, whether domestic, European, or Asian.

▲ DIAGNOSTIC EXERCISE

A technician has been asked to diagnose a vehicle with a 6-cylinder engine that runs rough at low RPM. He performs a cylinder power balance test using an ignition oscilloscope to disable the spark of each cylinder. When disabled, five of the cylinders cause a normal drop in engine RPM. However, when one of the cylinders is disabled, engine RPM *increases* substantially. Based on his training and experience, the technician decides to check out the EGR system. Explain how a faulty EGR system could cause this symptom.

Review Questions

1. What is the primary reason that a fuel injector's winding is kept immersed in liquid fuel?
   A. To cool the fuel before it is sprayed from the injector to reduce the potential for vapor lock
   B. To help atomize the fuel before the injector is energized
   C. To help prevent overheating of the injector's winding
   D. To provide electrical continuity through the fuel between the two ends of the winding to reduce the potential for an injector voltage spike
2. What is the purpose of controlling a peak and hold injector with two drivers?
   A. To provide a backup driver in case one driver fails
   B. To provide additional current for the total duration of the injector's pulse
   C. To provide good mechanical response without overheating the injector's windings
   D. To provide a diagnostic circuit for the PCM
3. Why are electric fuel pumps that are associated with fuel injection systems mounted in the fuel tank rather than in the engine compartment?
   A. To make replacement difficult so as to keep the vehicle owner from replacing it with an aftermarket pump
   B. To reduce the cost of replacing the fuel pump
   C. To increase the PCM's ability to diagnose the fuel pump circuits
   D. To reduce the potential for vapor lock within the fuel management system

4. Why is the PCM programmed to de-energize the fuel pump relay if the tach reference signal is lost?
   A. To guard against emptying the fuel tank through a ruptured fuel supply line
   B. To protect the winding in the fuel pump relay from overheating
   C. To protect the fuel pump from overheating
   D. To ensure that the ignition coil(s) will not overheat
5. In a PFI system with a return line, why is the fuel pressure regulator indexed to intake manifold pressure?
   A. To increase the rate of fuel flow through the fuel injectors when the engine is under high load
   B. To maintain a consistent rate of fuel flow through the injectors, regardless of engine load
   C. To reduce the rate of fuel flow through the injectors when the engine is under high load
   D. To ensure that the fuel injectors will not be able to supply fuel if the engine stalls and manifold vacuum is lost
6. Why have manufacturers begun using returnless fuel injection systems?
   A. To reduce the amount of heat that is carried from the engine compartment to the fuel tank
   B. To reduce the potential for evaporative hydrocarbon emissions to be produced within the fuel tank
   C. To reduce the potential for vapor lock within the fuel management system
   D. Both A and B
7. A technician is using a scan tool and notices that LTFT is at +8 percent (+.08). What is indicated?
   A. The PCM has learned to subtract fuel from the base fuel calculation to compensate for a lean condition.
   B. The PCM has learned to subtract fuel from the base fuel calculation to compensate for a rich condition.
   C. The PCM has learned to add fuel to the base fuel calculation to compensate for a lean condition.
   D. The PCM has learned to add fuel to the base fuel calculation to compensate for a rich condition.
8. All, except which of the following are methods used by the PCM to control idle speed?
   A. The PCM controls an actuator to manipulate the physical position of the throttle plate(s).
   B. The PCM sends a command signal to the crankshaft to tell it how fast to run.
   C. The PCM controls a stepper motor to control throttle bypass air.
   D. The PCM controls a solenoid on a duty cycle to control throttle bypass air.
9. Two technicians are discussing the design of a waste spark ignition system. Technician A says that the polarity of a waste spark coil is reversed each time it fires so that the negatively firing spark plug always ignites an air/fuel charge. Technician B says that a waste spark coil may be mounted directly on top of one of the spark plugs that it fires. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
10. Which of the following is an advantage of a COP ignition system?
    A. There is less potential for the secondary circuit to induce a voltage in a nearby circuit.
    B. It is easier to connect a secondary ignition oscilloscope to the system for diagnosis.
    C. The ignition coils used in this system no longer contain primary windings.
    D. This system uses a pick-up in a distributor, thereby allowing base timing to be adjusted.
11. Which level of information, as described in this chapter, is required for the PCM and/or ignition module to fire the correct ignition coil in a waste spark ignition system?
    A. First level; identifying "*a pair* of cylinder pistons are approaching TDC"

B. Second level; identifying "*which pair* of cylinder pistons are approaching TDC"
C. Third level; identifying "*which cylinder* of the piston pair approaching TDC is on the compression stroke"
D. None of the answers above provides enough information for the correct ignition coil to be fired.

12. Which level (or levels) of information, as described in this chapter, may originate at a CKP sensor?
    A. The first level only
    B. The first and second levels only
    C. The second and third levels only
    D. The first, second, and third levels
13. Two technicians are discussing the design and use of a grounded shield. Technician A says that it is used to protect the primary ignition circuitry from the potential induction of a voltage signal caused by a nearby circuit. Technician B says that it consists of a bare wire that is grounded at one end only and then, along with the other wires, is wrapped with aluminum foil. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
14. Which of the following is an advantage of placing the ignition module's equivalent inside the PCM?
    A. It is less expensive to replace the ignition module when it fails.
    B. The ignition module is able to more efficiently dissipate the heat that it produces.
    C. The effectiveness of the vehicle's antitheft disabling system is enhanced.
    D. The PCM's complexity is reduced.
15. While diagnosing an engine with COP and SFI systems that "will crank, but won't start," the technician finds that the ignition coils are producing spark, but no fuel injector pulse is present while cranking. Which of the following could *not* be the reason the engine fails to start?
    A. The CKP sensor has failed.
    B. The ignition module has failed in its ability to pass the tach reference on to the PCM.
    C. The tach reference wire between the ignition module and the PCM might be open.
    D. The PCM has failed.
16. TAC and EFE systems are designed to reduce which of the following emissions when the engine is cold?
    A. CO only
    B. HC only
    C. Both CO and HC
    D. NO_x
17. An evaporative and canister purge system is designed to prevent the release of which of the following emissions from the fuel tank to the atmosphere?
    A. CO
    B. HC
    C. CO_2
    D. NO_x
18. The primary purpose of the EGR system is to reduce which of the following emissions?
    A. CO
    B. HC
    C. CO_2
    D. NO_x
19. Technician A says that variable valve timing is designed to increase the high-performance capability of the engine while maintaining good driveability and emissions. Technician B says that a variable valve timing system, in some way, is designed to vary the relationship of the valve opening and closing to the crankshaft's position. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
20. All except which of the following are advantages of a 42-V system over a 14-V system?
    A. Many heavy-duty components that are traditionally belt-driven will likely be driven by a motor.
    B. A 42-V system is safer to work on than a 14-V system.
    C. Smaller diameter wiring can be used.
    D. A 42-V system is more likely to have 120-V power points mounted within the vehicle.

Chapter 5

Diagnostic Concepts

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Describe the two types of faults associated with automotive computer systems.
- ☐ Describe the two types of diagnostic trouble codes associated with automotive computer systems.
- ☐ Understand the function and purpose of a data stream.
- ☐ Understand the various types of functional tests that may be programmed into an engine computer.
- ☐ Recognize the function of a pinpoint test.
- ☐ Recognize the function of a flowchart.
- ☐ Understand the function and purpose of an electrical schematic.

KEY TERMS

Active Command
Bidirectional Controls
Data Stream
Diagnostic Trouble Code (DTC)
Electrical Schematic
Flowchart
Functional Test
Hard Fault
Memory DTC
On-Demand DTC
Parameter ID (PID)
Pinpoint Test
Self-Test
Soft Fault
Technical Service Bulletin (TSB)
Voltage Drop Test

Understanding the product-specific diagnostic methods in the manufacturer-specific chapters of this textbook may be a difficult task and may seem to require a large amount of memorization. But all these methods are based on the same fundamental diagnostic concepts. This chapter is designed to cover some of the basic concepts involved in diagnosing modern electronic engine control systems. Mastering the material in this chapter will promote your understanding of the manufacturer-specific chapters.

TYPES OF FAULTS

Soft Faults

A **soft fault** is commonly known as an *intermittent fault.* As a technician, you should always attempt to verify the symptom as the first step of diagnosis. If the symptom cannot be recreated, you are likely dealing with a soft fault. Following are some realistic tips for helping you diagnose a soft fault.

Diagnosing Soft Faults. It is possible that the engine computer, also known as the powertrain control module (PCM), has identified the problem and has set a **diagnostic trouble code (DTC)** in memory. For example, a problem of stalling on a hot day and then restarting after a 20-minute cool-down period can be the result of a faulty ignition module. It can also be the result of a faulty electric fuel pump or even a faulty fuel pump relay. Beginning in the mid- to late 1980s, feedback circuits were typically added to the PCM to assist the technician in identifying problem areas. Look for a memory fault code that might direct you to a particular area.

Normal procedures used to test load components and their circuits may be used to diagnose an intermittent fault even when the symptom does not appear to be present. If the symptom (or **memory DTC**) leads you to suspect an intermittent fault in a particular circuit (for example, the fuel pump circuit), try performing the following procedures.

If the intermittent problem is a fault within the circuitry, rather than a fault in the load component, you may be able to diagnose it through a **voltage drop test** (explained in Chapter 6). For example, if the switch (or relay-operated switch) that controls a circuit has built up excessive resistance in the contacts, this resistance will likely increase with an increase in temperature. The increased resistance reduces current flow in the circuit and may result in an apparent symptom. By the time you attempt to verify the symptom, the switch contacts may have cooled, reducing the effective resistance and increasing the current flow enough that the symptom appears to have disappeared. The unwanted resistance is still present in the switch contacts, however, and even though the current flow has increased enough to allow the load component to operate, it is still below the designed current value for this circuit. A voltage drop check of the circuitry can identify the unwanted resistance, even with no apparent symptom present. Although the measured voltage drop will not be as dramatic as when the symptom is present, it will still likely be above specifications. This procedure can also identify intermittent faults associated with a loose or corroded connection in the circuitry.

If the intermittent problem is in an electromagnetic load component, such as a solenoid, relay, or motor, current ramping (explained in Chapter 6) can help you identify the fault. If the intermittent fault is in an electronic module, such as an ignition module, using of a choke tester to heat (and cool) the module while watching for the symptom to resurface may help you identify the fault. You may also tap on electronic devices in an attempt to verify the problem.

Hard Faults

Hard faults are faults that are present when you attempt to verify the symptom. A hard fault is usually easier to diagnose than a soft fault, and simple use of the concepts explained in this chapter will usually identify the fault.

DIAGNOSTIC TROUBLE CODES

It is common knowledge that most PCMs can communicate to the technician alpha and/or numeric readouts that represent fault codes, but some additional explanation is required regarding the types of fault codes that can be obtained from a PCM. All manufacturers now refer to these fault codes as diagnostic trouble codes, or DTCs. The technician should always check the applicable DTCs when attempting to diagnose driveability, fuel economy, and emission concerns.

Memory DTCs

A memory DTC is a DTC that the PCM has stored in its RAM IC chip at some point in the past. The technician may be able to bring up the memory fault code either through manual code-pulling methods or with a scan tool, depending on the make and year of the vehicle. Most PCMs are programmed to erase the memory fault on their own if they do not see the fault reoccur after a preset number of restarts of the engine, or, in many instances, a preset number of warm-up and cool-down cycles of the engine as measured by the ECT sensor. A memory fault code may be either a soft fault or a hard fault. However, the fact that it is set in the PCM's memory does not necessarily mean that the fault is still present. If a pre-OBD II vehicle application has only memory code capability and more than one DTC has set in memory, you should first record and then erase all stored memory codes. Then drive the vehicle on a road test. Any DTCs that do not reset during the road test are likely soft faults; any DTCs that do reset during the road test are likely hard faults. After repair of a memory DTC, the technician should again erase the DTC from the PCM's memory to avoid inadvertently chasing an "already-repaired DTC" at a later time. Then the vehicle should again be road tested to verify that the DTC does not reset (except OBD II vehicles that require multiple drive cycles be driven to verify a repair; see Chapter 8).

On-Demand DTCs

An **on-demand DTC** is set as a result of the PCM running a **self-test** (performance test) of the system at the instruction of the technician. A self-test is defined as a test that the computer is programmed to perform on the system that it controls. The technician may be able to initiate a self-test either through manual methods or with a scan tool, depending on the make and year of the vehicle. After the technician initiates the self-test, the PCM puts the system through a variety of tests as it checks each circuit's ability to function. The resulting DTCs are hard faults in that the PCM has identified their existence and immediately reported the results to the technician. A PCM on a given application may be programmed to perform key on, engine off (KOEO), and key on, engine running (KOER) self-tests. In this case, it is important to perform both tests. The engine should be properly warmed up prior to running this type of test and all accessories should be turned off. Also, in some cases the technician will be asked to cycle certain switches at some point during the self-test to allow the PCM to check their operation.

The PCM will most likely perform checks of the electrical circuitry during the KOEO self-test and functional tests during the KOER self-test. For example, if the PCM controls the air-injection system (described briefly in Chapter 4) through vacuum solenoids, it may energize and de-energize these solenoids during the KOEO self-test while monitoring the voltage drop in these circuits. Then, during the KOER self-test, the PCM will perform a **functional test** of this system by energizing the solenoid valves and watching the oxygen sensor(s). For example, the PCM may hold the first solenoid valve energized so as to direct pump air to the second solenoid. Then it may energize and de-energize the second solenoid valve so as to direct pump air upstream (to the exhaust manifold) and downstream (to the oxidation converter). Then with the second solenoid valve held energized (upstream), the PCM may energize and de-energize the first solenoid valve, ultimately switching pump air to the upstream position and then dumping it to the atmosphere. With each test, each time the pump air is switched to the upstream position, the PCM expects to see the atmospheric air pumped in ahead of the O_2 sensors drive the primary O_2 sensor values lean. In this way, the PCM can test the secondary air system functionally. Functional tests may also be run during the KOER self-test for other components and systems, including components such as the knock sensor and systems such as the EGR system. Therefore, when these tests are built into the PCM's programming, it is not an option to run one test or the other; both tests should always be run, beginning with the electrical (KOEO) self-test, followed by the functional (KOER) self-test. In fact, repairs should be made for any KOEO hard faults before you even attempt to perform the functional self-test. Often, a KOER self-test cannot be completed successfully because electrical failures still exist. In such cases, a repair must be sold by the service writer to the customer before testing can be completed. This is not the result of a failing on the part of the technician, but rather is due to the complexity of the modern vehicle and the way that systems interact with each other. The customer understandably will want to know the total dollar amount that the repairs will cost on the first phone call, but often this is simply not practical.

Another point to note concerning on-demand tests: "current condition matters." For example, for an engine system self-test, the engine should be properly warmed up, all accessories should be turned off, and other manufacturer-specific instructions should be adhered to prior to performing the self-test. When these conditions are not properly met, false DTCs may be recorded. This does not apply to those systems that do not perform on-demand tests but only allow the technician to pull memory DTCs. For example, it does not matter whether the engine is warmed up or not if the technician is only pulling codes from the computer's memory that set "sometime last week"—such memory codes are unaffected by current condition.

On vehicles manufactured prior to OBD II, an on-demand DTC does not set in the PCM's memory; therefore, you cannot really erase it from memory in the way that you would erase a memory DTC. Instead, you must make the indicated repair and rerun the self-test. If the repair was successful, the DTC will not reset. (Some OBD II PCMs will now retain in memory a failure DTC that is set as the result of a self-test.)

Also, if the application has both self-test and memory code abilities (as in the Ford EEC IV and EEC V systems described in Chapters 13 and 14), a simple comparison of the types of faults received will allow you to know which faults are hard and which are soft without having to erase the memory faults and road test the vehicle. Remember, while a memory DTC may be either soft or hard, a DTC that is set as a result of a self-test is a hard fault. Therefore, on those systems that have both abilities, a memory DTC that also sets following either self-test is a hard fault, but a memory DTC that does not set following the self-tests is likely a soft fault.

DATA STREAMS

A **data stream** is information about a computer system that is delivered via serial data from the PCM (or other control module) to your scan tool (see "Scan Tools" in Chapter 6). The PCM believes this information to be true about the system that it controls. There is no manual method to access this type of information, which comes from the PCM's memories in the form of binary code. This information may include memory DTCs, input voltages and/or PCM-interpreted values, output commands, fuel trim numbers (see "Fuel Trim" in Chapter 3), PROM ID numbers, and other types of information. The information accessed in a data stream is identified by the **parameter ID (PID).** A data stream PID may identify an input value from a sensor, an output command to an actuator, or some other piece of information such as the PID for the long-term or short-term fuel trim values.

FUNCTIONAL TESTS

Functional tests are tests that the PCM has been programmed to perform, but the test results are usually not rendered by the PCM. Most often, it is up to the technician to determine the pass/fail result of each functional test. Functional tests are usually used in specific circumstances to aid in diagnosing specific problems and are not used on every vehicle that comes in the door. Many times, a **flowchart** will guide the technician to a specific functional test.

For example, a common functional test is an **active command.** Through the use of an active command, the technician may be able to command the PCM to energize and de-energize certain actuators or to perform other test procedures, such as an engine power balance test. While most active commands on modern vehicles are quite sophisticated and require the use of a scan tool, some early, low-level active commands could be performed using jumper wires and other manual methods. On modern vehicles, performing an active command involves the use of the scan tool to send commands to the PCM (or other control module); these commands are known as **bidirectional controls.**

There is a strong similarity between an active command and an on-demand self-test: Both will cause the PCM to turn actuators on and off. But with an on-demand self-test, the PCM (or other control module) also determines pass/fail during the test and has the ability to set a failure code following the test. With an active command, the control module does not make a pass/fail determination; rather, it is up to the technician to determine whether the computer can properly activate the output.

Another advantage of an active command: If the control module can successfully activate the actuator, it can serve as an excellent component locator. For example, if two identical relays are mounted on the firewall next to each other and you want to know which one is the cooling fan relay, simply use a scan tool to issue a bidirectional command to energize and de-energize the cooling fan relay and feel which relay is "clicking."

TECHNICAL SERVICE BULLETINS

When manufacturers are alerted to a problem on their vehicles, often they will issue a procedure to help the technician repair the problem properly. This is known as a **technical service bulletin (TSB).** TSBs are the manufacturers' method of alerting technicians to problems that they have become aware of as well as their recommended "fix." The manufacturers make available to their dealership technicians the ability to report problems that have not already been addressed. The manufacturer will then issue a TSB that addresses the problem and instructs the technician on how to perform a proper repair so as to correct the problem.

TSBs are issued with regard to many types of problems, including driveability problems, steering and suspension problems, brake problems, wind noise concerns, and so on. TSBs concerning engine control systems may involve anything from the relocation of a wiring harness so as to reduce electromagnet interference (EMI) problems in a circuit to the replacement of a sensor/actuator with a new part number; they may even involve the reprogramming (reflashing) of the PCM. TSBs are also available to aftermarket technicians through most electronic service manuals and information systems. The technician should always check for applicable TSBs when attempting to diagnose driveability, fuel economy, and emission concerns.

PINPOINT TESTING

After a DTC has been retrieved to direct the technician to a general area or circuit, the identified circuit must undergo a **pinpoint test** to determine the exact fault. Bear in mind that connectors and wires can set the same DTCs that a defective input sensor or output actuator can set. Some early systems did not have any self-diagnostic ability programmed into the PCM, thus requiring that the entire computer system be pinpoint tested by the technician when a symptom was encountered. While this can be a huge undertaking, fortunately many of these early systems were not as complex as later systems. Still, this can be quite a daunting task.

Pinpoint testing may include performing a voltage drop test of the PCM's power and ground circuits with the PCM powered up, testing the circuitry that connects the PCM to each of its sensors and actuators, and testing each of the sensors and actuators for proper operation. The pinpoint test procedure should ultimately determine the exact repair needed so that the technician can identify for the customer what is required to properly repair the vehicle. Often, the pinpoint test procedure may identify a particular fault that the customer must be made aware of before overall testing is complete. Because identified faults should be repaired before continuing with the diagnostic procedure, the technician may have to contact the customer more than once if multiple faults exist.

Method of Performing Pinpoint Tests

When using a digital volt-ohmmeter (DVOM) or a lab scope, also referred to a digital storage oscilloscope (DSO) (discussed in Chapter 6), to perform pinpoint tests, some point of electrical contact must be made between the meter's leads and the circuit being tested. It is always recommended that a set of jumper leads be connected between the circuit and the component while taking care not to allow these leads to contact each other.

For example, if a DTC directs you to test the throttle position sensor (TPS) circuit, you can purchase or manufacture a set of three jumpers with the appropriate male and female terminals. Disconnect the sensor's three-wire connector from the sensor and install these jumpers between the harness connector and the sensor. Then, after turning on the ignition switch, simply touch the meter's leads to the jumpers' male/female metal terminals to take measurements of the reference voltage supplied to the sensor, the signal returned by the sensor, or the voltage drop of the ground circuit that completes the sensor's circuit to the battery. When the tests are complete, simply turn off the ignition switch and disconnect and remove the jumpers, then reinstall the harness connector to the sensor. When making voltage drop tests of the computer's power and ground circuits, because of the large number of wires in these connectors, do not use individual jumper wires (inadvertent shorts would occur). Rather, you should use a breakout box (BOB) (discussed in Chapter 6) to access these circuits. No connectors or wiring insulation have been damaged or compromised when these procedures are used.

An alternative approach (although often abused) is to use a T-pin (available at the fabric/sewing center of major retail stores) to back-probe the terminal at the sensor or actuator. This is *not* considered a recommended method, but because this method is so commonly used in the industry and will likely continue to be used, the following discussion is included in hopes of minimizing any damage resulting from its use.

When using a T-pin to back-probe an electrical connector, carefully slide the T-pin into the plastic body of the electrical connector beside and *parallel to* the wire coming out of the connector until you feel it touch the metal terminal of the connector (Figure 5–1). Then take the applicable measurement with your DVOM or DSO. If done properly and carefully, this approach minimizes the damage done to the wire's copper and insulation as well as to the connector while providing a relatively easy approach to making pinpoint measurements. (While this method does work well with many types of electrical connectors when done properly and carefully, it is not recommended for use with weather-pack connectors [discussed in Chapter 10] because it will compromise the weather-pack seal. With this type of connector, it is best to use the method of connecting temporary jumper wires, as described earlier.)

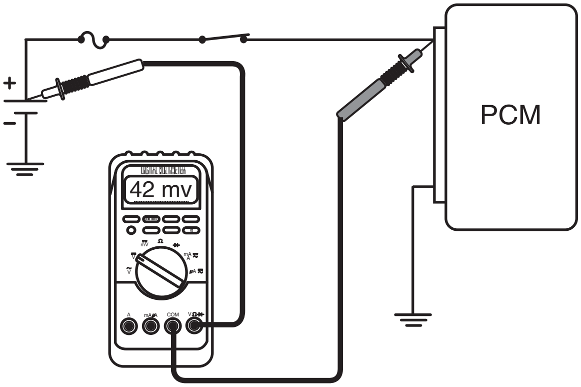


Figure 5–1 Performing a positive-side voltage drop test.

CAUTION: When back-probing, *do not* poke the T-pin *through* the wire at an angle perpendicular to the wire (Figure 5–1)—this compromises the wire's insulation and will also break copper strands of the wire, thus increasing the resistance of the wire at the point of the damage. Many voltage drop problems can be traced to someone who previously worked on the vehicle and damaged the wiring when making pinpoint tests.

CAUTION: When back-probing, *do not* probe directly into a component, such as an O_2 sensor, where the wire exits the

sensor—always perform the back-probing at an electrical connector.

CAUTION: When back-probing, *do not* use more than one T-pin at a time in the same connector—if the T-pins were to touch each other, the load may be bypassed and the computer that controls the load may be damaged. Many damaged control modules can be traced to someone who previously worked on the vehicle using improper procedures.

CAUTION: *Do not* ever use back-probing as a diagnostic method on systems that operate at a voltage above 14 V. Systems that operate at 42 V and higher require other forms of diagnostic tools such as BOBs. Refer to manufacturer recommended procedures.

CAUTION: *Do not* use T-pins to probe the terminals in the data link connector (DLC). You will enlarge these terminals. This will result in the inability to use a scan tool to communicate with the on-board computers in a reliable fashion, causing either intermittent communication or a total loss of communication. Instead, use a BOB designed for the DLC (discussed further in Chapter 6).

CAUTION: When using a DVOM or DSO to pinpoint test a circuit, *never* insert the meter's leads directly into a female terminal. You will enlarge it and thus create a faulty connection when it is reconnected.

Pinpoint Testing of a Sensor

When a DTC directs you to a sensor or sensor circuit, always consider that there are two possibilities: (1) the sensor or sensor circuit is faulty and should be replaced or repaired, or (2) the sensor and its circuit are operating correctly but the value that is being measured by the sensor is less than ideal. For example, a coolant temperature gauge might read "hot" because of a faulty gauge/sender/circuit, but it could also read "hot" simply because the engine is truly overheating. And so it is with the sensors in a computer system.

An "O_2 always rich" code can be generated because of a faulty O_2 sensor or circuit problem, but the same DTC can also be generated because the engine air/fuel ratio is truly running rich, in which case replacing the sensor would solve nothing. In this case, one method to verify whether there is a problem with the O_2 sensor would be to use an exhaust gas analyzer (discussed in Chapter 7) to determine whether the air/fuel ratio was truly rich.

Similarly, a MAP sensor that reports the engine is under partial load when it is at idle in the service bay could be the result of a faulty MAP sensor. But it could also be the result of low engine vacuum being made available to the MAP sensor due to a restricted or leaking vacuum line, or even low vacuum being produced by the engine, in which case, again, replacing the sensor would not solve the problem. Find out by teeing a vacuum gauge into the line going to the MAP sensor.

Pinpoint Testing of a Load Component

Pinpoint tests of most load components can be broken down into two categories: electrical tests and functional tests. Using a solenoid-operated valve as an example, electrical tests might include the following:

- Test the resistance of the solenoid's coil and compare to specification (checks for both shorted windings as well as open windings).
- Energize the solenoid with jumper wires and note the "click." (This does not constitute a functional test, as it does not test the valve for flow or leakage.)
- Capture a current waveform with an oscilloscope (discussed under "Current Ramping" in Chapter 6).
- Some service manuals also advise, with the solenoid's harness connector disconnected from the solenoid, using a jumper wire to

jumper battery voltage to one side of the solenoid and then using a DVOM to measure the voltage at the other terminal (should be source voltage). However, while this tests the winding for an open, it does *not* test the winding for shorts. A resistance test with an ohmmeter is a better test.

These same tests might also be used to test the winding of a relay electrically. For example, with a Bosch relay, simply make a resistance test between terminals 85 and 86. (When applying power and ground to energize a diode-suppressed relay, be sure to carefully observe the correct polarity to avoid burning the diode open.)

Follow the electrical tests with a functional test. The functional test will test whether the load component performs its function properly. The type of test involved depends on the type of load component involved. For example, with a fuel pump motor, you might test the fuel pressure and volume with the motor energized and driving the pump. Or with a TBI fuel injector, you might simply watch it—with the system pressurized and the engine not running, it should not leak; and with the starter cranking the engine, it should spray fuel. With a vacuum solenoid, you might use a vacuum pump opposite a vacuum gauge to test when the solenoid does and does not allow vacuum to be transferred from the pump to the gauge. With a relay, you might use it to power another circuit while testing the voltage drop across the contacts when they are closed. With a Bosch relay, test the voltage drop across terminals 30 and 87 when the relay is energized and being used to power a light bulb (a 12-V test light will work as a load for purposes of the voltage drop test). Also, if applicable, test the voltage drop across terminals 30 and 87a when the relay is de-energized and being used to power a light bulb.

Voltage Drop Testing the PCM's Power and Ground Circuits

All too often, technicians overlook the voltage drop test of the PCM's power and ground circuits (Figures 5–2 and 5–3). As with any electronic device, if either the power or ground circuit is faulty, the PCM cannot function properly. With the ignition key turned on, engine not running (KOEO), the maximum battery-to-PCM power or ground voltage drop should never exceed 100 mV. (See Chapter 6 for additional information on performing voltage drop tests.)

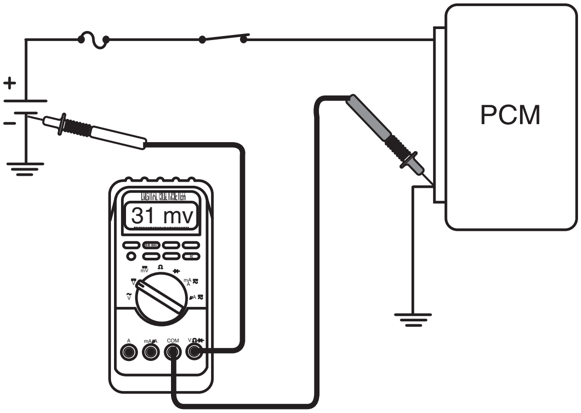


Figure 5–2 Performing a negative-side voltage drop test.

A PCM (or other control module) must have a minimum of 9.6 V (typical) dropped across it in order for its internal voltage reference regulator to continue to supply the module's internal circuits with a 5-V reference signal. This means that the difference between the positive and negative circuits must be at least 9.6 V. If not, the logic gates (discussed in Chapter 2) will cease to function properly and what is otherwise a good computer may appear to make wrong decisions. Replacing the computer will not repair the problem because it is not the computer that is at fault. Each of the following situations can cause an otherwise good computer to stop functioning properly:

- Battery open circuit voltage (OCV) is below 9.6 V.
- Battery is fully charged to 12.6 V, but there exists more than 3 V of combined voltage drop between the power and ground circuits

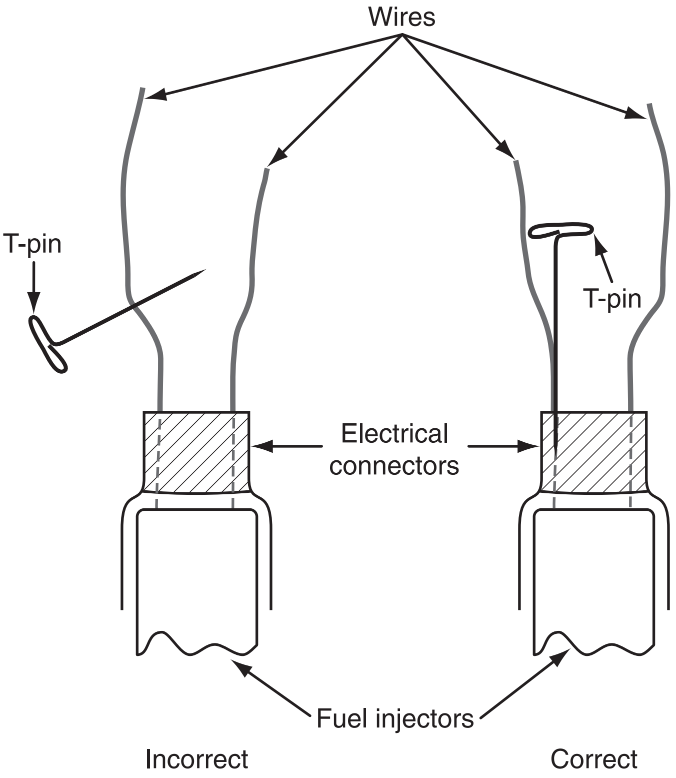


Figure 5–3 Incorrect and correct methods of using a T-pin to back-probe an electrical connector.

used to power up the computer, leaving the computer with less than 9.6 V voltage drop across the computer itself.

- Battery is fully charged to 12.6 V, but there exists more than 1 V of combined voltage drop between the computer's power and ground circuits used to power up the computer, thus leaving less than 11.6 V of voltage drop across the computer itself. Then you turn the ignition key to "start" and engage the starter motor. The current draw of the starter motor pulls battery voltage lower by another 2 V (down to 10.6 V), which, when combined with the more than 1 V of voltage drop in the power and ground circuits, leaves less than 9.6 V to be used up (dropped) by the computer itself. Thus, the PCM cannot even pulse a fuel injector when the engine is cranking, even though the battery is full charged.

You can see that unwanted voltage drop in a computer's power and ground circuits can easily cause a good computer to stop functioning properly. If you suspect that this might be a problem, remember that, while the reference voltage from the reference voltage regulator is sent to both the computer's internal circuitry and logic gates, it is also sent to various external sensors such as the TPS. When diagnosing computer system problems, always verify that a voltage signal close to 5 V is being sent successfully from the PCM to the TPS (some manufacturers specify between 4 V and 6 V should be present, but this author believes it should be closer to 5 V—between 4.8 V and 5.2 V). Another point to note: A voltage drop problem on the ground side of the computer can result in reference voltage that is too high. Also, be sure to verify the reference voltage signal while using the starter to crank the engine.

FLOWCHARTS

In most cases, either a symptom or a DTC can direct the technician to a flowchart that can assist the technician in making pinpoint tests efficiently. A flowchart instructs the technician to perform a specific pinpoint test and note the results. Depending on the results, it may either direct the technician to another specific pinpoint test or to make a specific repair. If all the steps in a flowchart are designed to fit on one page, it is commonly known as a *troubleshooting tree* (Figure 5–4). Figure 5–5 shows a manufacturer-specific flowchart. Today, in most paper service manuals, the flowchart sequence will typically have the technician flipping back and forth through multiple pages of the service manual as the diagnostic steps are followed, as opposed to fitting all test steps on a single page. With electronic service and information systems, the flowcharts are typically written in paragraph form and will direct you to certain paragraphs, while skipping others, depending on each test result.

When following a flowchart, the technician should begin with the particular step, as indicated by either the DTC or the symptom. It is critical at this point to read the flowchart's test instructions carefully and to perform the test exactly as described. It is equally important to be sure of the condition of any diagnostic tools used in each test step. If a required jumper wire has no continuity or if a DVOM lead has an intermittent connection, you may be led to an incorrect test step, resulting in a misdiagnosis of the system. Also, equally important, do not skip any test steps or assume their outcome. Some test steps may seem difficult to perform, but skipping a test step can also result in misdiagnosis of the system or wasted time if you end up starting your tests over again.

ELECTRICAL SCHEMATICS

When manufacturers design a flowchart, it is through their understanding of how the system is designed to operate that they are able to instruct

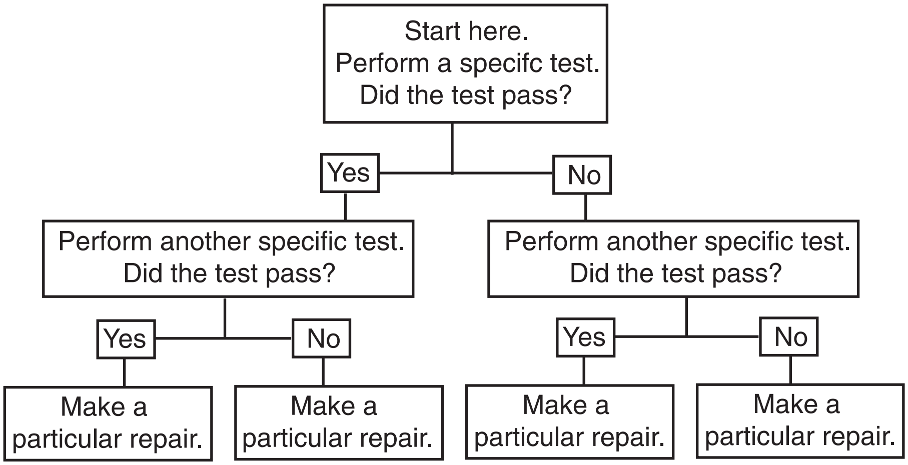
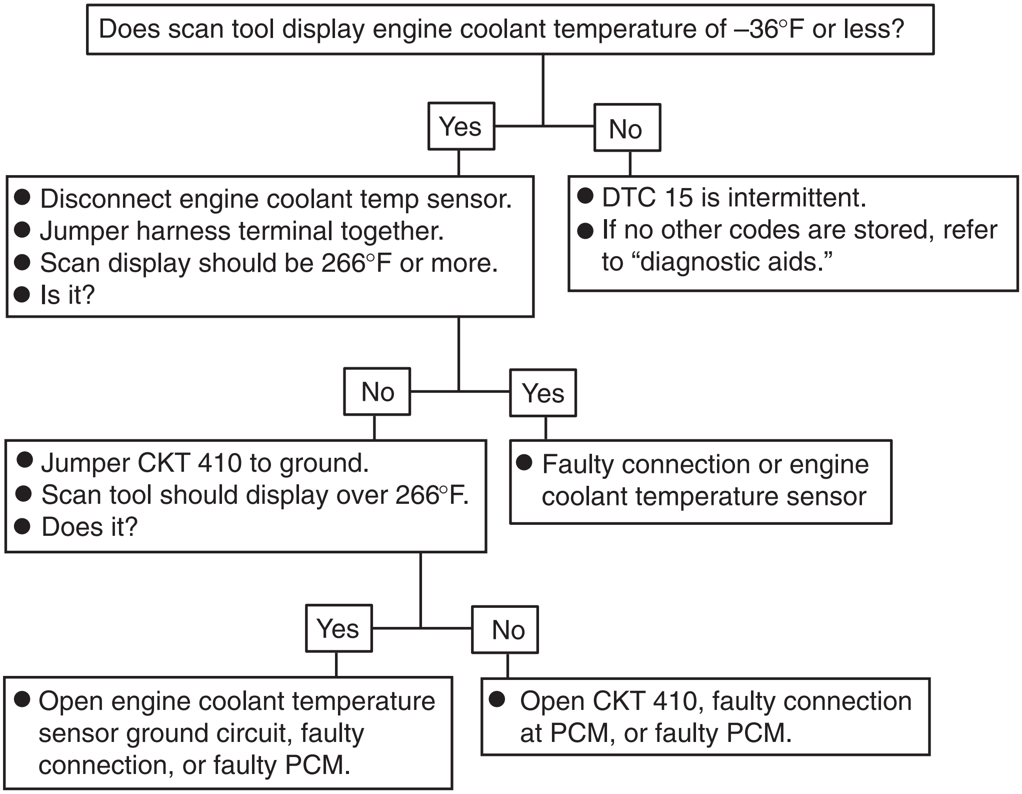

Start here.
Perform a specifc test.
Did the test pass?
Yes
No
Perform another specific test.
Did the test pass?
Perform another specific test.
Did the test pass?
Yes
No
Yes
No
Make a particular repair.
Make a particular repair.
Make a particular repair.
Make a particular repair.

Figure 5–4 Typical form of a troubleshooting tree.

DTC 15
Engine coolant temperature sensor circuit
(Low temperature indicated)



Does scan tool display engine coolant temperature of –36°F or less?

- Disconnect engine coolant temp sensor.
- Jumper harness terminal together.
- Scan display should be 266°F or more.
- Is it?

- DTC 15 is intermittent.
- If no other codes are stored, refer to “diagnostic aids.”

- Jumper CKT 410 to ground.
- Scan tool should display over 266°F.
- Does it?

- Faulty connection or engine coolant temperature sensor

- Open engine coolant temperature sensor ground circuit, faulty connection, or faulty PCM.

- Open CKT 410, faulty connection at PCM, or faulty PCM.

Diagnostic Aid

Temperature vs. Resistance Values (Approximate)

°C	°F	
100	212	177
80	176	332
60	140	667
40	104	1459
20	68	3520
0	32	9420
–20	–4	28,680
–40	–40	100,700

Figure 5–5 Diagnostic flowchart for locating the cause of an ECT sensor DTC.

the technician as to what tests should be performed for each of the possible symptoms and/or DTCs. Likewise, the technician should attempt to understand how a system with which he or she is unfamiliar is designed to operate. Part of your ability to do this lies in understanding each of the concepts outlined throughout this textbook, from simple inputs, processing, and outputs to the more detailed descriptions in various chapters of how each of the systems functions. However, your diagnostic ability will be increased if you are also able to interpret the **electrical schematic** for the system you are attempting to diagnose. In fact, many flowcharts incorporate an electrical schematic for this purpose.

Many electrical schematics are simple, dedicated schematics. Others are complicated by the fact that an otherwise simple schematic is part of a larger schematic, such as one that shows the circuits for the entire vehicle. Even a dedicated schematic may be complicated simply because of the technology involved. As you practice interpreting electrical schematics, be guided by the following recommendations, which will simplify even the most complex schematics.

The first thing that is important in interpreting an electrical schematic is to identify the components. If you are using a paper service manual, make a copy of the schematic on a copier; if your are using an electronic service manual, simply print out the electrical schematic. Then use a highlighter to identify the components and specific circuits. Taking the time to identify the components not only gives you some immediate insight into the system, but it will also keep you from inadvertently attempting to interpret the outline of a control module or other component as a circuit. Second, identify sources of power and grounds. Then you should identify any input circuits to a control module, output circuits from a control module, and data circuits between control modules on a network.

Certain complex electrical schematics will always be a challenge to any technician, no matter the level of experience. But as you practice interpreting electrical schematics, you will find that they become noticeably easier to read. If you take the time to compare the verified symptom to your understanding of system operation based on the system's electrical schematic, you will be able to narrow down the area where you need to begin testing the system. This is essentially what a flowchart does for you. However, it is not recommended that you use an electrical schematic *in place of* a flowchart, but rather *with* a flowchart to enhance your diagnostic abilities.

OTHER GENERAL DIAGNOSTIC CONCEPTS

Not all faults (either soft or hard) will actually generate a DTC, particularly in the early engine computer systems. The PCM was programmed to monitor the system for total failures or those failures that resulted in a voltage value outside the parameters programmed into the PCM. For example, a TPS could actually have an intermittent glitch that would not set a DTC in the PCM's memory because the voltage did not fall below the lower parameter that is programmed into the PCM, but it would still result in a lean hesitation each time it was encountered. By the late 1980s, the PCM had the ability to compare certain sensors and determine if a fault existed even if the voltage was not outside the parameter values. OBD II (discussed in Chapter 8) took this concept further, and the ability of the PCM to monitor the system for efficiency as well as for failure became a standard that applies to all OBD II vehicles. As a result, the PCM on newer vehicles is more often able to alert the technician through a DTC. In addition, as technology progressed, the PCM was enabled to monitor more functions through additional feedback circuits. Therefore, on a newer vehicle, a DTC can direct the technician to a more specific area than on some of the older systems. However, no matter how specific the area that a DTC is able to direct you to, you should always verify any fault through pinpoint testing. Also, bear in mind that multiple DTCs should be repaired in the order specified by the manufacturer.

SUMMARY

This chapter presented the basic concepts pertaining to diagnosing an engine computer system: hard faults and soft faults, memory code pulling and self-tests, and several other concepts that are used by the manufacturer's systems and that will be discussed throughout the remainder of this textbook. Understanding the concepts that constitute the building blocks of the various diagnostic programs should make it easier for the reader to comprehend the various concepts as the manufacturer-specific systems are covered.

▲ DIAGNOSTIC EXERCISE

A vehicle is towed into the shop because it "cranks, but won't start." The malfunction indicator lamp (MIL) does not come on, and all attempts to pull DTCs result in "no response." When a scan tool is connected, it cannot seem to communicate with the PCM. What tests should the technician do next?

Review Questions

1. What is a soft fault?
   A. A fault that exists intermittently
   B. A fault that is currently present
   C. A fault that can only be identified through the use of a scan tool
   D. A fault that cannot be properly diagnosed
2. What is a hard fault?
   A. A fault that exists intermittently
   B. A fault that is currently present
   C. A fault that can only be identified through the use of a scan tool
   D. A fault that cannot be properly diagnosed
3. What is a memory DTC?
   A. A fault code that sets in the PCM's memory during normal driving conditions
   B. A fault code that must be erased from the PCM's memory after it has been properly repaired
   C. A fault code that sets as a result of a self-test initiated by the technician
   D. Both A and B
4. What is an on-demand DTC?
   A. A fault code that sets in the PCM's memory during normal driving conditions
   B. A fault code that must be erased from the PCM's memory after it has been properly repaired
   C. A fault code that sets as a result of a self-test initiated by the technician
   D. Both A and B
5. Technician A says that some engine computer systems allow the technician to pull memory DTCs. Technician B says that some engine computer systems allow the technician to pull memory DTCs and initiate performance self-tests of the system. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
6. Which of the following statements concerning a data stream is false?
   A. It consists of serial data (binary code) coming from the PCM.
   B. It includes information about input sensor values.
   C. It includes information about output actuator commands.
   D. It can be interpreted with manual methods, such as through using a voltmeter.
7. The values obtained through a data stream are identified as to the type of value that is represented by which of the following?
   A. TID
   B. VID
   C. PID
   D. CID
8. Which of the following statements concerning a funcational test is false?
   A. It is a test that is programmed into the PCM.
   B. It should be used on every vehicle that comes in the shop for a tune-up.

C. It is designed to aid the technician in identifying specific problems.
D. A flow chart may direct the technician to perform a functional test.

9. When manufacturers are alerted to a particular problem on their vehicles, many times they will issue a procedure to help the technician repair this problem properly. This is known as which of the following?
A. DTC
B. DLC
C. TSB
D. TAB

10. Which of the following statements concerning a pinpoint test is false?
A. It is designed to direct the technician to the general area of the problem.
B. It is designed to help the technician identify the exact fault.
C. It may include testing the sensors and actuators, as well as the related circuitry.
D. It may include performing voltage drop tests of the PCM's power and ground circuits.

11. A vehicle is in the shop for diagnosing a fuel economy complaint. When the memory DTCs are pulled from the PCM, an "O_2 sensor is always lean" code is received. Technician A says that this means that the O_2 sensor is faulty and should be replaced without wasting any time on further testing. Technician B says that this code does not necessarily mean that the O_2 sensor is faulty. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

12. Two technicians are discussing the proper procedures to test a vacuum solenoid. Technician A says that the solenoid may be tested electrically by measuring the winding's resistance or by energizing the solenoid with jumper wires and noting the "click." Technician B says that the solenoid may be tested functionally by energizing and deenergizing the solenoid while using a vacuum pump and a vacuum gauge to test the solenoid's ability to allow or block the flow. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

13. Two technicians are discussing a problem vehicle on which the engine will crank, but will not start. Technician A says that the voltage signal on the reference voltage wire coming from the PCM to the TPS should be approximately 5 V. Technician B says that if the voltage on the reference voltage wire between the PCM and the TPS is too low, the PCM is faulty and should be replaced without further testing. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

14. Which of the following statements concerning a flowchart is false?
A. It is designed to assist the technician in making pinpoint tests to identify the exact fault.
B. The technician may be directed to a certain step of a flowchart by reason of a DTC.
C. The technician may be directed to a certain step of a flowchart by reason of a symptom.
D. It is okay to skip a test step in a flowchart and assume the test result if the test step is too difficult to perform.

15. Which of the following statements concerning an electrical schematic is false?
A. It can aid a technician in understanding how a system is designed to operate.
B. It may show components, power and ground circuits, input and output circuits, and data stream circuits.
C. It should be used with a flowchart for maximum diagnostic potential.
D. There is nothing to be gained from taking the time to follow an electrical schematic because flowcharts are always 100 percent accurate and should therefore be used alone.

Chapter 6

Diagnostic Equipment

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ❑ Describe the types of equipment that may be used in diagnosing symptoms associated with computerized engine control systems.
- ❑ Understand the functional concepts and procedures associated with each type of diagnostic tool.
- ❑ Interpret the readings associated with each type of diagnostic tool.
- ❑ Understand the advantages, disadvantages, and limitations of each type of diagnostic tool.

KEY TERMS

Amplitude
Breakout Box (BOB)
Current Ramping
Digital Storage Oscilloscope (DSO)
Digital Volt-Ohmmeters (DVOM)
Logic Probe
Motor Start-Up In-Rush Current
Non-Powered Test Light
Scan Tool (Scanner)
Trigger

Your noblest efforts to properly diagnose today's electronic systems may be limited by your knowledge of the diagnostic tools available to you as a technician. This chapter is designed to enhance your understanding of today's tools, their purpose and function, and their limitations.

SCAN TOOLS

A **scan tool** (or **scanner**) is probably the most familiar tool to anyone working with today's computerized systems. Figures 6–1 and 6–2 show typical scan tools. However, it is important to recognize the distinct abilities of a scan tool. Let us begin by covering the purposes of a scan tool.

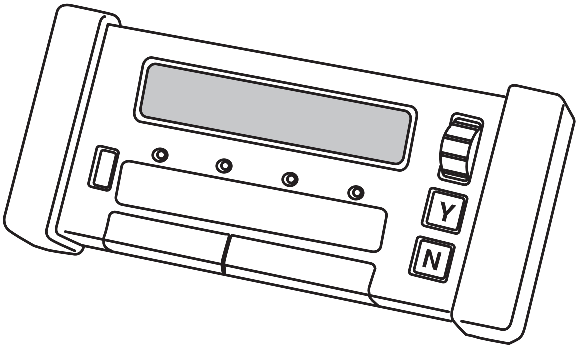


Figure 6–1 A typical scan tool that can be used to retrieve data stream information from the PCM.

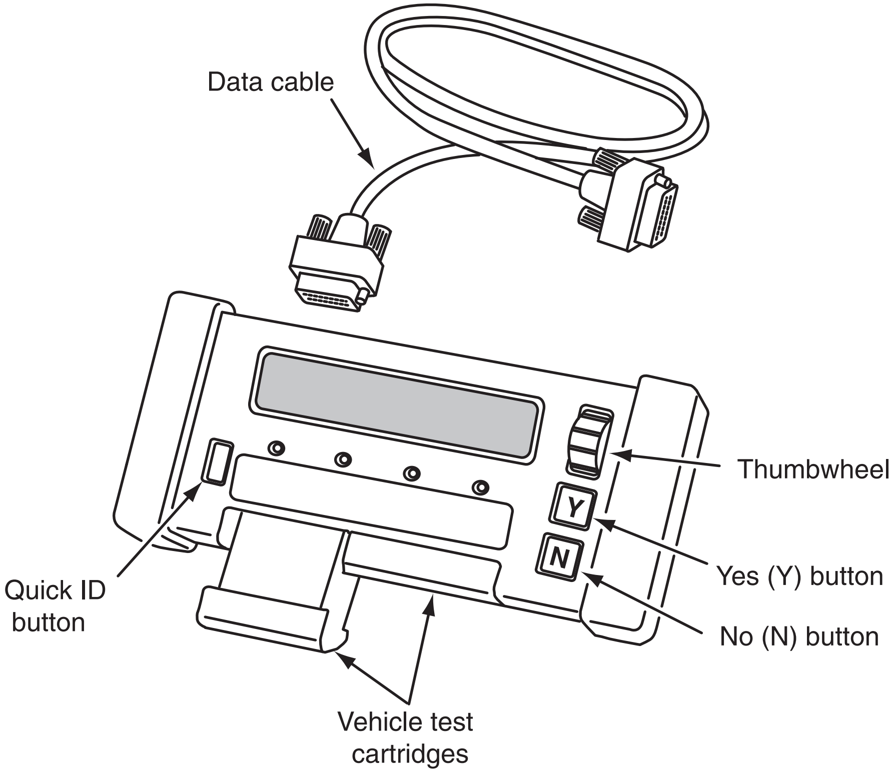


Figure 6–2 This aftermarket scan tool features plug-in modules for various years and makes. The data cable can accommodate both pre-OBD II and OBD II vehicles by means of adaptors.

Purpose

Code Pulling. A scanner's ability to pull codes includes both pulling DTCs from a computer's memory and causing the computer to perform a self-test of the system and display the resulting DTCs. In certain early applications in which code pulling cannot be done with a scan tool but must be accomplished through manual methods, the scan tool may still have the ability to instruct the technician as to the proper procedure, even though it cannot be connected to the system.

Functional Tests. Scan tools can also be used to perform functional tests that the vehicle manufacturer has programmed into the on-board computer. Some scan tool manufacturers refer to these tests as *special tests.* The primary and best-known functional test is the *active command mode,* in which the scan tool is able to use its *bidirectional controls* to command on-board control modules to perform certain actions, such as energizing a cooling fan relay or a canister purge vent solenoid.

A common use of such a test is to help the technician quickly narrow a problem down to the input side or the output side of the computer. For example, if the electric cooling fan does not come on during normal vehicle operation, resulting in an over-heating condition of the engine, a scan tool may be used to command the PCM to energize the cooling fan relay. If the cooling fan then runs, the output side of the computer has been eliminated as a possible fault and the technician knows that the problem is likely on the input side—either a coolant temperature sensor or its associated wiring. However, if the cooling fan does not run during this test, then the technician knows that the problem is likely on the output side of the computer and can proceed by testing the cooling fan relay, the cooling fan motor, and the associated wiring.

Another purpose of this test is simply to provide an easy method of energizing an actuator when the need arises for the sake of other testing procedures. For example, the technician may use a scan tool to command the PCM to energize the normally open canister purge vent solenoid when using a leak tester to test the evaporative system for leaks. This closes the solenoid and thus enables the system to hold pressure. This ability eliminates the need for energizing the solenoid manually using jumper wires in order to leak test the system.

As you read about the specific systems in the remaining chapters of this book, you will occasionally encounter other functional tests as well, such as the ability to command the PCM to perform a cylinder power balance test.

Data Stream. Scan tools can read data stream information from the on-board computers. This information includes the *computer's interpretation* of input sensor values, including both the perceived voltage and the interpreted value. For example, the engine coolant temperature (ECT) information may be displayed as a voltage (0.62 V) and as the interpreted temperature that it represents (205°F or 96°C).

The scan data also shows the computer's *intended* output commands. It is always a good idea to check whether the intended commands are actually being carried out.

Scan data will also display other pieces of information from the computer's memory. This includes information such as fuel trim values and PROM ID numbers.

Scan data, whether input data, output commands, or other data, is identified as to subject area by the information's parameter ID (PID). Data stream PIDs include inputs identified as "ECT volts," "ECT temperature," "O_2 sensor volts," and so on. Output PIDs might include commanded "fuel injector pulse width" or commanded "spark advance." Each PID will be displayed with a corresponding value.

Finally, scan data may be customized on many scan tools. This ability allows the technician to select only the PIDs that he/she wishes to look at. This speeds up the scan tool's update rate because the PCM (or other control module) no longer has to communicate all the available information to the scan tool. As fast as it might be, it still holds true that the binary communication (serial data) between the PCM and the scan tool can only communicate one PID and its value at a time, so reducing the amount of information being communicated increases the update rate of the remaining information.

Additional Features

Many scan tools provide additional features such as a data capture mode (sometimes called a *snapshot* or *movie mode*) for use in identifying causes of intermittent symptoms. When attempting to verify an intermittent problem, this mode may be used to capture data while road testing the vehicle. When the symptom is felt, this data can be frozen within the scan tool, and it can be reviewed later, frame by frame, while watching the input/output values at the point where the symptom occurred.

Other additional features may include idle reset and/or idle RPM control through the scanner, octane adjustment, tire size input for vehicle speed sensor (VSS) calibration, and the ability to disable or enable certain features for various systems. Additionally, some scan tools provide an internal source of information (electronic shop manual) including DTC meanings, module pinouts, and term definitions.

Purpose and Functional Concept

Scan tools are designed to communicate with the on-board computers using serial data (binary code). When connected to a data link connector or a diagnostic link connector (DLC), the scan tool actually becomes a node on the data bus and can typically communicate with any other node (or module) on the bus. The amount of information that can be accessed through a scanner varies among scan tool manufacturers. The vehicle manufacturer's scan tool is, of course, the most capable unit. Generally, aftermarket scan tool manufacturers are more limited in their capabilities. However, a technician working in an independent repair shop will usually find that the aftermarket scan tool is the best investment.

Functional Procedure

A scan tool simply plugs into the DLC after it has been equipped with the correct adaptor. Once powered up, it requires vehicle identification number (VIN) and data input from the technician. (Some OBD II applications will automatically configure the VIN code entry once the scanner is connected to the DLC and the ignition is turned on.) This automatically sets the scan tool to the baud rate of the modules on the data bus. Then the technician must select the module to be diagnosed, as well as the desired menu item, such as memory DTCs; key on, engine off (KOEO) self-test; key on, engine running (KOER) self-test; functional tests; and data stream.

Functional Interpretation

When looking at scan tool data, bear in mind that the scan tool only offers the computer's interpretation of the data. For example, input values are measured at the computer and are subject to errors induced by faulty connections, as well as poor computer power and ground connections. Output commands indicate the computer's intentions and, most often, cannot compensate for defective drivers, poor connections, and deficient actuators.

For example, a discrepancy between an input voltage value shown on a scan tool and a raw voltage signal when measured at the sensor may occur because of computer power and ground voltage drop problems. Scan data that indicates an actuator is energized may be simply the result of the computer attempting to forward bias the driver that controls the circuit. Many problems have been overlooked because a technician blindly believed that the intended output command had successfully been carried out simply because the scan tool had indicated it.

Advantages

A scan tool has the advantage that it is easy to connect and can very quickly give the technician a very large amount of information. In addition, the display typically provides a written menu and instructions that make the tool very easy to use.

Disadvantages and Limitations

Although a scan tool may offer a very quick approach to diagnostics, it can only direct you to a problem *area* or circuit. It cannot tell you the exact cause of a symptom. For example, if it shows that a temperature circuit is sending a 5-V signal to the computer (equating to approximately −40°F), your understanding of an NTC thermistor circuit tells you that the circuit is open. This open could be in the sensor, a wire, a connector, or the PCM itself. To identify the exact cause of the open circuit, further pinpoint testing is needed.

Again, when a computer informs you via a scan tool that an action has been commanded, this means only that the computer is attempting to forward bias the output driver (transistor) that controls this action. It does not really know (in most cases) whether the action has in fact taken place. The exception would be on those systems that monitor the output function with a feedback signal. This is more common in newer systems, particularly those that are OBD II compliant, or in safety systems such as an antilock braking system (ABS). Certain output circuits have been monitored on Ford computerized systems since 1980, such as EGR operation or those circuits that are tested during a KOEO or KOER self-test.

Scan tools are also limited in their ability to identify intermittent problems of short duration. The update speed of a scan tool's data is limited according to the PCM's baud rate. Only one PID and its corresponding value can be updated with each binary communication. This increases the probability that a glitch in a TPS circuit, for example, may happen between scan tool updates and therefore may never be seen by the technician who is using a scan tool.

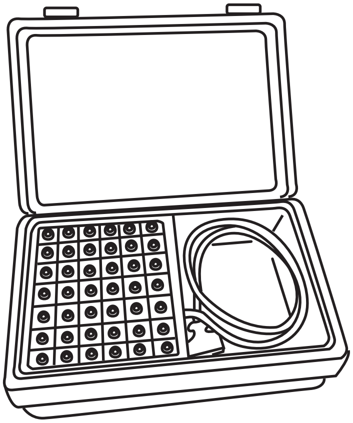


Figure 6–3 A typical BOB that can be used to pinpoint test a computer's circuits.

BREAKOUT BOXES

A **breakout box (BOB)** (Figure 6–3) is a diagnostic tool introduced in the 1980s, primarily to diagnose Ford computerized engine control systems. Many technicians equated it to a scan tool, but a BOB has a totally different function and purpose than a scan tool, and the technician is best served by access to both diagnostic methods. As a result, today, other manufacturers and systems have BOBs designed to help in diagnosis, and aftermarket universal BOBs have become widely available.

Purpose and Functional Concept

A BOB gives the technician a central testing point to make pinpoint tests of input sensors, output actuators, and associated wiring, as well as computer power and ground voltage-drop tests—all without back-probing. It connects into the harness between the PCM and the harness connector. As a result, it makes all computer circuits entering or exiting the PCM accessible to your **digital volt-ohmmeters (DVOM)** or **digital storage oscilloscope (DSO)** while maintaining the functionality of the computer system.

Functional Procedure

Carefully disconnect the PCM from the harness connector. Then connect the harness connector to the proper BOB connector. Make only this connection and leave the PCM disconnected if you need to make resistance checks of the circuits or if you will be using jumper wires to test actuators from the box. (Of course, due to their low resistance and high current potential, do not ever use jumper wires to manually energize high-energy ignition coils or low-resistance fuel injectors.) Connect the PCM to the BOB for the system to be fully functional for testing voltage, frequency, duty-cycle on-time, or pulse-width on-time. Then use a **logic probe,** DVOM, or DSO to probe the designated pins on the BOB, depending on which circuits you need to test.

Functional Interpretation

Tests made with a BOB indicate raw data (voltage, voltage drop, resistance, frequency, duty cycle, or pulse width). Therefore, they verify not only the input sensors or output actuators but also the circuitry that connects these components to the PCM.

Advantages

When used in conjunction with a voltmeter or oscilloscope, a BOB provides the user with a single location to access all circuits for testing without back-probing. Test results are actual values, not computer-interpreted values. This author fully believes that BOBs are slated to increase in popularity as the automotive world encompasses higher voltage systems such as the 42-V systems already in use on some vehicles. These systems do not allow for any back-probing whatsoever as a diagnostic method, so the BOB will be required to access the computer power and ground terminals for making voltage-drop tests.

Disadvantages and Limitations

Depending on the particular vehicle application, it can be quite time consuming to connect

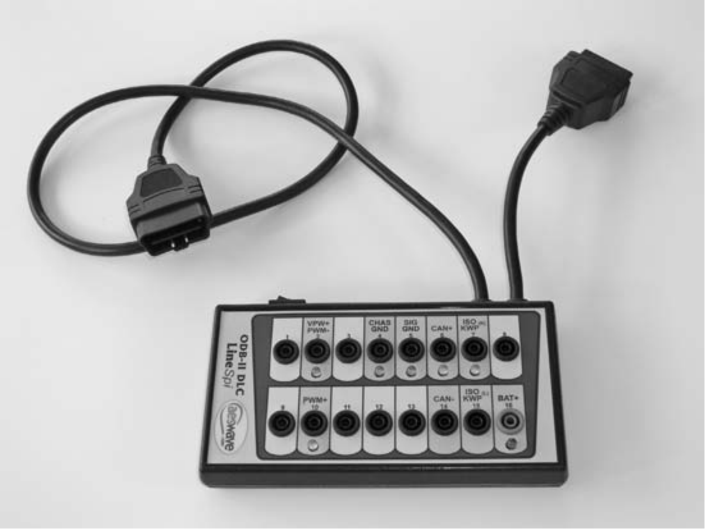


Figure 6–4 DLC breakout box.

a BOB into the system. Also, a BOB cannot be used to identify things in the computer's memory such as a PROM ID number, fuel trim values, or how an octane adjustment has been set with a scan tool.

BOBs for the OBD II DLC

Breakout boxes designed for use with the OBD II DLC are now commonly available (Figure 6–4). When such a unit is connected to an OBD II DLC, it not only allows for probing of the 16 terminals with a meter's leads, but most allow for a simultaneous connection of a scan tool to the opposite end. In this manner, a DVOM or DSO may be used to read raw signals while attempting to communicate with a scan tool. "Smart" units are also equipped with light-emitting diodes (LEDs) that indicate the availability of power and ground to the appropriate terminals as well as the presence of serial data on the appropriate terminals. OBD II DLC breakout boxes are available from such providers as AESWAVE (http://www.aeswave.com) and Automotive Test Solutions (http://www.automotivetestsolutions.com).

NON-POWERED TEST LIGHTS

Non-powered test lights (Figure 6–5) continue to have a place in your toolbox for certain quick checks. However, many technicians continue to use these devices in circuits where they can be very dangerous; therefore, it is important to understand a few facts about them.

Purpose and Functional Concept

The test light's only purpose is to serve as a quick-check tool to show if a voltage potential is

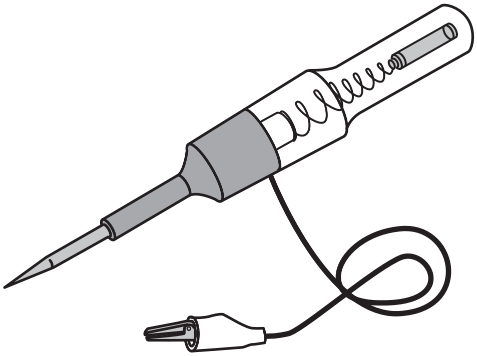


Figure 6–5 A typical non-powered test light.

present. A voltage differential across the test light causes the bulb to glow.

Functional Procedure

Begin by connecting the test light across the battery's terminals to verify the integrity of the test light. Then, while it is grounded, touch the circuit in question and note the light. A test light makes a great tool for testing all of the vehicle's fuses in a short amount of time. It can also be used to test switching of circuits such as ignition coils and fuel injectors as long as the resistance of the test light equals or exceeds the resistance of the intended load. A grounded test light can also be used to provide a path of low resistance for identifying poor insulation in secondary ignition wiring. Secondary ignition wiring that is arcing to ground can be difficult to identify in the shop when cylinder pressures are low and resistance across the plug gap is also low. But many times, even with the engine idling, a secondary wire will arc to a grounded test light to help identify the specific insulation breakdown. For this test, pass the tip of the grounded test light along each of the secondary wires with the engine running.

Functional Interpretation

The fact that a test light illuminates proves only that a voltage potential is present. In situations in which accurate voltage readings are required, you should never try to guess by the bulb's brightness how much voltage is present.

Advantages

The advantages of a test light are that it is easy to use, it is inexpensive, and it takes up very little room in your toolbox. Although it has several limitations, it makes a great quick-check tool for several initial tests as you begin diagnosing certain types of faults.

Disadvantages and Limitations

A test light cannot indicate voltage values; therefore, there are many tests that it cannot perform. For example, it would not be a good tool to use in performing voltage-drop tests. Additionally, it has great potential for damaging electronic circuits. If the test light's resistance is less than the intended load, it will draw more current than the circuit was designed to carry. This can destroy a module's output driver. Many computers have been destroyed because someone used a test light to read code output manually. These circuits are generally designed to let you count codes manually using an analog volt-ohmmeter and were not designed to carry the current that a test light draws and are thus destroyed by the use of a test light. Also remember that use of a test light on an airbag system can result in accidental deployment of the airbag(s). For all practical purposes, think of a test light as a jumper wire.

LOGIC PROBES

A logic probe (Figure 6–6) is basically a test light that is safe for use on today's vehicles because it has high resistance designed into its

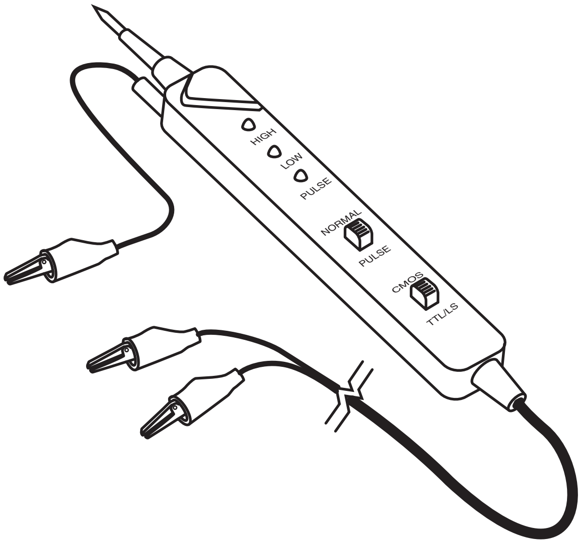


Figure 6–6 A logic probe is an excellent tool for testing for the presence of electrical signals.

internal circuitry. In fact, the term *logic probe* implies that it was designed for use with today's computers. Logic probes are generally available from electronics suppliers at a reasonable price. You can also purchase similar devices known as *high-impedance test lights* from tool suppliers.

Purpose and Functional Concept

Like a test light, a logic probe provides the technician with a quick-check tool. Once powered up, a logic probe can be used to check for voltage and ground potential. It is also excellent for testing for the presence of switched signals within the primary ignition system or at the fuel injectors.

Functional Procedure

As an electronic device, a logic probe must first be powered up. To do this, connect the power leads to battery positive and negative. Then, for best results, connect the tip's negative lead to a clean unpainted ground. (The ground lead in the power lead set contains a protective diode that influences the ground level if it is the only ground used.) If the logic probe has a CMOS/TTL switch, set it as follows: For working with voltages from 0 to 12 V, set it to CMOS, and for working with voltages from 0 to 5 V, set it to TTL. Then set the NORMAL/PULSE switch as follows: When it is set to NORMAL, the red and green (LEDs) will indicate high- or low-voltage levels within the selected voltage range and a tone generator emits a high or low tone; when it is set to PULSE, a yellow LED is also used to indicate a *pulsed* voltage signal. Unfortunately, the yellow LED is also lit by induced voltage from the secondary ignition wires if you are in close proximity to them on a running engine.

The alligator clips may be cut off and replaced by soldering in a cigarette lighter adaptor (while paying attention to the required polarity). In this configuration, a logic probe can be quickly powered up using a power point in the passenger compartment for the purpose of electrically testing fuses. The plug can still be connected quickly to the vehicle's battery through the use of a cigarette lighter female socket-to-alligator clips adaptor.

Functional Interpretation

With the tip of the probe connected to the circuit in question, note the LEDs. The red LED (and high tone) responds to a higher voltage, whereas the green LED (and low tone) responds to a lower voltage. The brightness of one LED compared to the other can also give you a rough indication of duty-cycle on-time versus off-time. If you have the probe connected to the ground side of a ground-side switched actuator, increasing the on-time increases the brightness of the green LED.

Advantages

A logic probe is an easy-to-use tool best suited for determining the presence (or loss) of primary ignition and fuel injection signals. It also has high internal resistance and is therefore safe for use in diagnosing electronic circuits.

Disadvantages and Limitations

A logic probe, like a standard test light, cannot inform you of exact voltage values or voltage-drop readings, and it is therefore limited to certain quick checks.

DIGITAL VOLT-OHMMETERS

A DVOM is used by most technicians to make pinpoint tests of the computer and its associated circuits and components. A typical manual-scaling DVOM is shown in Figure 6–7 and a typical automatic-scaling DVOM is shown in Figure 6–8.

Purpose and Functional Concept

A DVOM is generally the tool of choice for making accurate pinpoint tests of the electrical characteristics of a circuit. When purchasing a

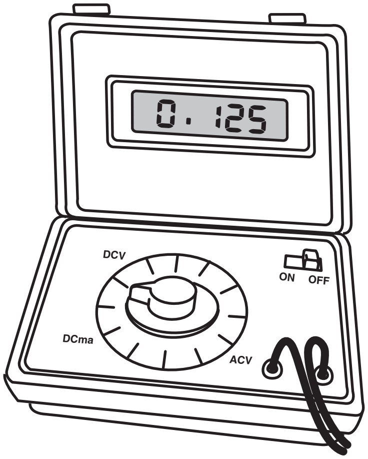


Figure 6–7 A typical manual-scaling DVOM.

DVOM, look for the following features: resistance, AC and DC voltage, AC and DC current flow, frequency, duty-cycle on-time, pulse-width on-time, temperature, and RPM. Also, you might want a bar graph, a min and max function, a hold function, and an average function. If the DVOM is auto-scaling, also look at the unit's response time (in the specifications sheet) or how long it takes for the DVOM to sense the signal, rescale, and display the reading. This time can range from 2 seconds on some low-end units to 100 milliseconds (ms) or faster on high-end units. The DVOM should also be rated at no less than 10 MΩ impedance when scaled to a DC voltage scale. This high resistance through the meter ensures that it does not damage electronic circuits, and meter accuracy is increased when measuring DC voltage. Bear in mind that when the DVOM is functioning as an ammeter, it effectively acts as a jumper wire.

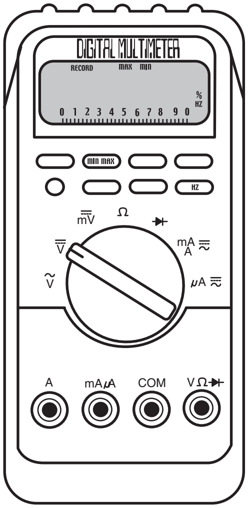


Figure 6–8 A typical automatic-scaling DVOM.

A DVOM is designed to provide in-depth information about the electrical characteristics of a circuit. However, all too often, technicians get careless in their interpretation of what they see on the DVOM's display screen and misdiagnose a problem.

Functional Procedure

A DVOM has an easy two-lead connection. Connect the black lead to the jack marked "Common" and the red lead to the jack marked for the type of measurement needed. Bear in mind that leads connected into the amp jacks effectively turn the DVOM into a jumper wire. Now set the dial to the scale needed. Connect the red and black leads to the circuit or component that you need to test, according to the type of measurement being made (voltage, voltage drop, amperage, or resistance). The red lead should connect to the point that is most positive in the circuit and the black lead to the point that is most negative. If the DVOM is a manual-scaling unit, for best accuracy be sure to scale down to the lowest scale that can read the value being measured. Then note the reading on the display and interpret the reading according to the type of scale to which the DVOM is currently set. Bear in mind that with each scale that a DVOM is scaled upward the reading becomes less accurate by a factor of ten. Some DVOMs are auto-scaling (auto-ranging) in that the DVOM will automatically rescale itself to the correct scale to be used as the leads are connected to a circuit or component. On an auto-scaling meter, be sure to verify which type of scale has been selected (K, M, m, or µ) in the DVOM's display window.

Even with an auto-scaling DVOM, many times it is to your advantage to manually scale the meter, in which case the same rules should be followed as for a manually scaled meter. For example, it would be better to manually scale a DVOM to a 20-V scale when making measurements in a circuit such as a TPS circuit that operates within a 0-V to 5-V range as opposed to having an auto-scaling meter rescale itself from a 2-V scale to the 20-V scale as the voltage climbs above 2 V. This automatic rescaling is sometimes misinterpreted as a fault.

Functional Interpretation

Because a DVOM provides very exact measurements of raw data, it makes an excellent pinpoint test tool. But particular attention must be paid to the scale's factor when interpreting the reading on the display. This factor may be shown on either the scale selection dial or on the display, depending on the particular DVOM. A "K" (kilo) means that whole numbers represent "thousands" and an uppercase "M" (mega) means that whole numbers represent "millions." The decimal point should be moved three or six places to the *right,* respectively, to convert these values to numbers that represent single whole units. Likewise a small "m" (milli) means that whole numbers represent "thousandths" and a "µ" symbol (micro) means that whole numbers represent "millionths." The decimal point should be moved three or six places to the *left,* respectively, to convert these values to numbers that represent single whole units. If a factor value is not shown on the scale selection or the display, read the display as it appears. The ability to use a DVOM on any type of scale (ohms, amps, volts, Hertz) depends on the technician's ability to interpret these factors. Figure 6–9 shows the four most common factors used with DVOMs. Figure 6–10 shows four sample interpretations of these factors.

PREFIX (Factor)	**SYMBOL**	**RELATIONSHIP TO BASIC UNIT**
Mega	M	1,000,000
Kilo	K	1000
Milli	m	1/1000
Micro	µ	1/1,000,000

Figure 6–9 The four most common DVOM scale factors.

1.234 MΩ = 1,234,000 Ohms
1.234 KΩ = 1234 Ohms
1,234 mA = 1.234 Amps
1,234 µA = 0.001234 Amps

Figure 6–10 Examples of converting each of the factors to the base unit.

DC Voltage versus AC Voltage

A DVOM that is set to the DC voltage scale will measure the *average* voltage of a rapidly switched voltage. If, with the alternator ripple considered, the voltage that is applied from the alternator to the vehicle's battery with the engine running varies from 14.1 V to 14.3 V, a DC voltmeter would interpret this signal as 14.2 V. Similarly, if a DC voltmeter is used in an attempt to measure the AC voltage produced by a wheel speed sensor in an ABS, no matter how fast you spin the wheel, the measured voltage will always be near zero volts because the average of an AC voltage is zero. Unfortunately, this mistake could lead the technician to falsely believe that the sensor was defective. And if you connect a DC voltmeter to an actuator that is operated on a duty cycle, cycling from zero volts to about 14 V, an average voltage of about 7 V would be indicative of a 50 percent duty cycle.

An AC voltmeter works differently and is much more complex. When the DVOM is set to the AC voltage scale, the meter looks at the **amplitude**

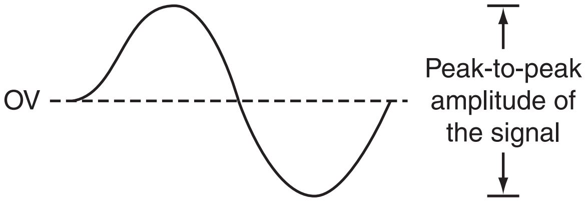


Figure 6–11 Sinusoidal AC voltage.

of the signal. The amplitude is the difference between the highest value and the lowest value. If the meter's leads are connected to an AC wall outlet, the meter will see the voltage go positive by a value of about 170 V and will then see the voltage go negative by a value of about 170 V. Thus, the amplitude of the signal, or peak-to-peak voltage, is about 340 V. The AC voltmeter uses an algorithm to obtain the DC equivalent value, or how much work is getting done when compared to a DC voltage. This is done by multiplying the 170-V value (either positive or negative) by a factor of about 0.707 to obtain a resulting value of about 120 V.

If the AC voltage is a sine wave (known as a *sinusoidal waveform*) (Figure 6–11), the DC equivalent value can be accurately measured and calculated by either a standard AC voltmeter (known as an *average responding* meter) or with a true RMS meter. ("RMS" stands for *Root Mean Square,* which refers to the algorithm used to obtain the DC equivalent value.) However, if the AC voltage is not a sine wave (known as a *non-sinusoidal waveform*) (Figure 6–12), the true RMS meter will measure and calculate the DC equivalent value of the AC voltage with greater accuracy than an average responding meter is capable of.

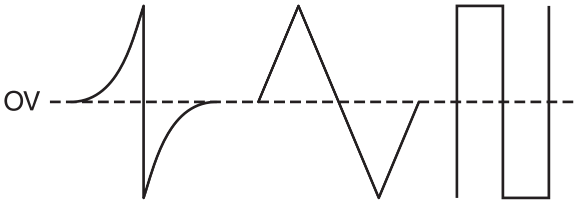


Figure 6–12 Examples of non-sinusoidal AC voltages.

The difficulty in measuring an unstable voltage (such as an AC voltage) and calculating its true working value stems from the fact that it is constantly changing and never remains at one voltage value for very long. A true RMS meter is able to do this by calculating the heat energy loss (measured in wattage) when the current is pushed by the voltage through a fixed resistance within the meter. In essence, the meter compares this energy loss to the energy loss that would be created by a DC voltage pushing current across the same resistance. Thus, the true RMS meter is able to accurately calculate the DC equivalent value of both sinusoidal and non-sinusoidal AC voltages with equal accuracy. In comparison, an average responding AC voltmeter, while capable of an accurate measurement of a sinusoidal AC voltage, is unable to measure a non-sinusoidal AC voltage with the same accuracy that a true RMS AC voltmeter does. As a result, an average responding AC voltmeter will generally display a lesser voltage value than its true RMS counterpart when measuring non-sinusoidal AC voltages.

This does not mean that you necessarily need to replace your average responding AC voltmeter with a true RMS meter. Automotive manufacturers wrote many of their AC voltage specifications knowing that most technicians were using average responding AC voltmeters. And with most AC voltage generating sensors, the computer does not react to "how much AC voltage is produced." Instead, what is important to the computer is the "frequency of the voltage pulses" and "when the voltage pulse occurs." Either type of AC voltmeter is capable of determining whether an AC voltage generating sensor is capable of producing enough voltage (in terms of its amplitude) to be able to be recognized as a voltage pulse by the computer.

Testing Available Voltage with a DVOM

If the DVOM's negative lead is connected to the negative terminal of the battery, the DVOM's positive lead can be used to test for available voltage

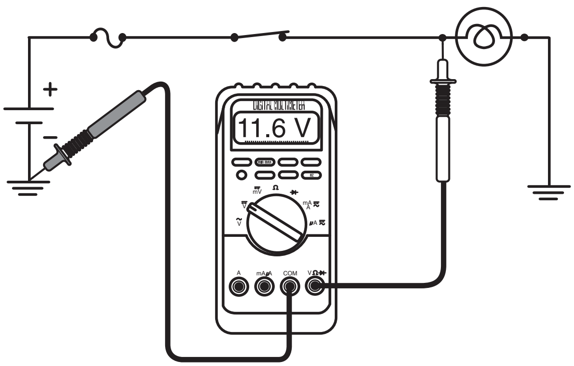


Figure 6–13 Available voltage test.

at any point in a circuit (Figure 6–13). If the positive lead is connected to the positive terminal of the battery, the battery's open circuit voltage (OCV) is measured. While these are easy tests, many technicians limit their testing to this, ignoring the increasingly important art of voltage-drop testing.

Voltage-Drop Testing with a DVOM

A circuit always consists of three parts: the source, the load component, and the connecting circuitry, on both the positive and negative sides of the circuit. When a symptom of poor operation (or even no apparent operation at all) is encountered, the source should always be checked first. This, of course, is the vehicle's battery if the engine is not running. When the engine is running, the alternator (actually, the rear half of the alternator since that is where the rectifier bridge is located) becomes the voltage source.

The second item that should be tested is the connecting circuitry, which is responsible for supplying the load component with as close to the full amount of the source's voltage potential as possible. There are exceptions to this, however. Some examples are:

- the current-limiting resistors used for the low and intermediate speeds of a blower motor control circuit (Figure 6–14A)
- the resistor (ballast resistor) that was used to limit current flow through the ignition coil of many ignition systems a few years ago (Figure 6–14B)
- the current-limiting resistor used in a temperature-sensing circuit (Figure 6–14C)

While testing voltage drop across a circuit, you should remember that:

- In an ideal circuit, all of the voltage drop should take place across the load component.
- In an ideal circuit, none of the voltage drop should take place across the circuitry.
- Voltage drop cannot occur unless the circuit is complete and current is flowing in the circuit.
- Voltage that is dropped (used up) is always the result of resistance encountered when current is flowing in the circuit and therefore proves the existence of resistance in the circuit.
- Voltage measurements can then be used to identify the existence of unwanted, excessive resistance in the circuitry, but only if the circuit is complete and at least some current is flowing in the circuit, even if it is not sufficient current flow to cause the load component to appear to operate.

To perform a voltage-drop test of a circuit, the DVOM must be connected in *parallel* to the circuitry, either on the positive (insulated) side of the circuit or on the negative (ground) side of the circuit. If you are performing a voltage-drop test on the insulated side of the circuit with the KOEO, the DVOM should be connected *between* the battery positive post and the load component's positive terminal with the positive DVOM lead connected to the battery. This parallel connection compares the difference between the two voltage values and displays the results (Figure 6–15). This difference is the amount of voltage drop that has occurred between the two points where the DVOM's leads are connected. This reading equates to having measured the available voltage at the battery, then having measured the voltage reaching the load, and then mathematically figuring the difference, assuming that the battery voltage did not change during the time that the two voltage readings were taken.

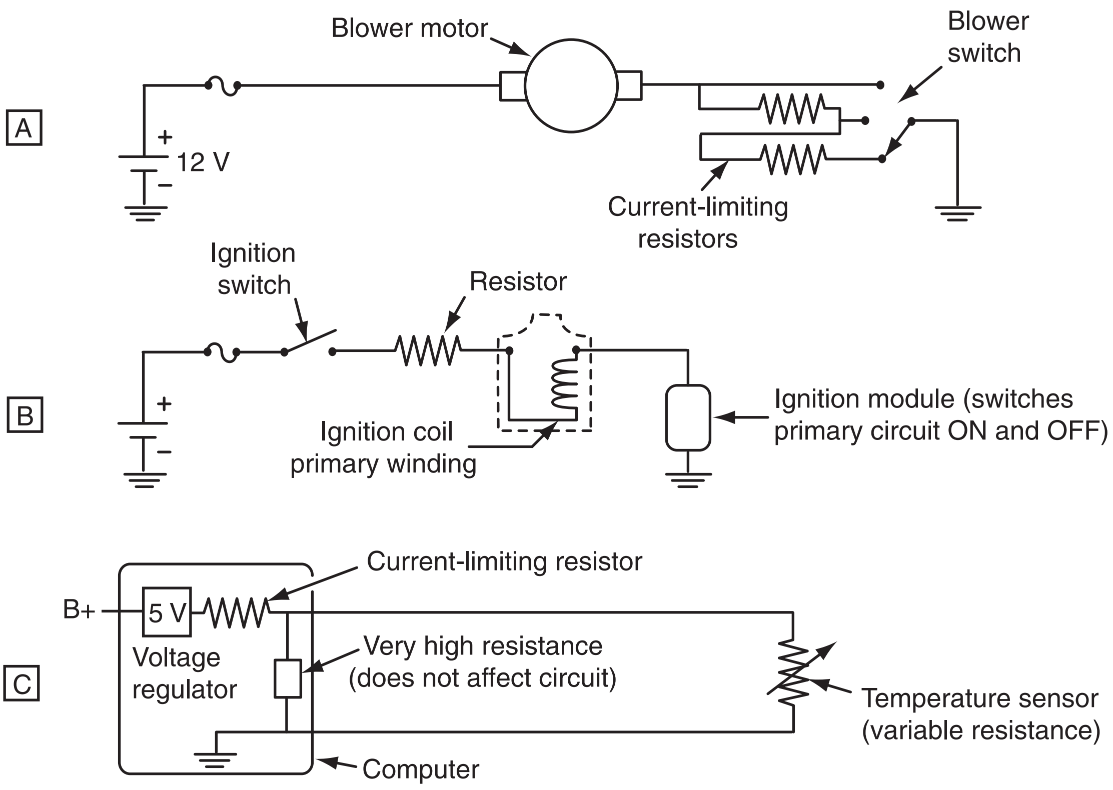

A
Blower motor
Blower switch
+
12 V
−
Current-limiting resistors
B
Ignition switch
Resistor
+
−
Ignition coil primary winding
Ignition module (switches primary circuit ON and OFF)
C
B+
5 V
Voltage regulator
Current-limiting resistor
Very high resistance (does not affect circuit)
Temperature sensor (variable resistance)
Computer

Figure 6–14 Current-limiting resistor circuits.

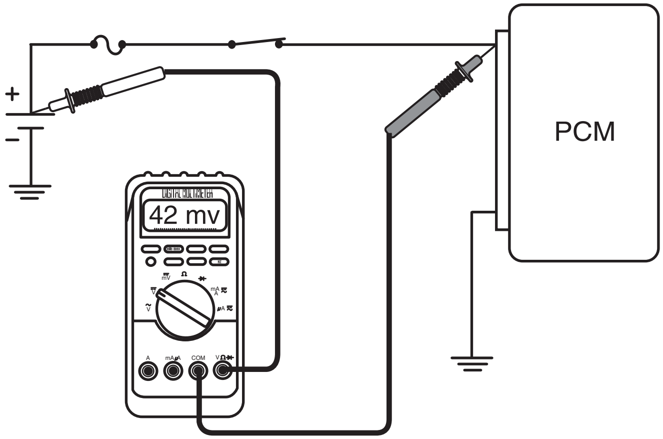


Figure 6–15 Positive-side voltage-drop test. A 0.042-V reading indicates that insulated circuit resistance is acceptable.

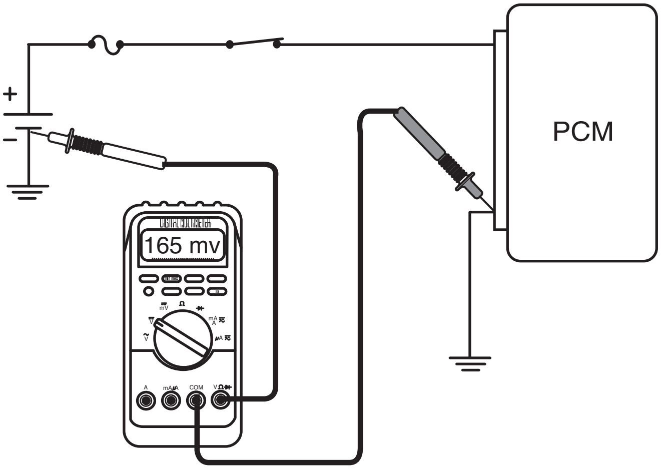


Figure 6–16 Negative-side voltage-drop test. A 0.165-V reading indicates excessive resistance in the ground-side circuit and is above acceptable limits.

If you are performing a voltage-drop test on the ground side of the circuit (KOEO), the DVOM should be connected *between* the battery negative post and the load component's negative terminal with the negative DVOM lead connected to the battery. Again, this parallel connection compares the difference in the two voltage values and displays the results (Figure 6–16). This difference is, again, the amount of voltage drop that has occurred between the two points where the DVOM's leads are connected and equates to how much voltage was left in the circuit after the load due to unwanted resistance in the circuit after the load.

Performing voltage-drop tests is the most accurate and efficient method to verify the integrity of the circuitry that connects the source to the load; it will alert the technician if excessive unwanted resistance exists in any part of the circuitry, be it in the wiring, any circuit protection devices, any switches (whether relay-operated or not), and any ground connections (either to engine, body, or chassis ground).

Depending on the type of circuit being tested, the specifications for allowable voltage drop vary, not because we allow more or less resistance for different types of circuits but primarily because more amperage across a given resistance results in more voltage drop and less amperage across a given resistance results in less voltage drop. This is due to the fact that all the source voltage will be used up evenly by each ohm of resistance value in a circuit. A high-amp circuit has less resistance, so each ohm of resistance produces more voltage drop; a low-amp circuit has more resistance, so each ohm of resistance produces less voltage drop. As a result, the typical maximum allowable voltage-drop specifications are as follows:

- most circuits = 0.1 V (100 mV) per connection
- starter circuits = 0.2 V (200 mV) per connection
- computer power and ground circuits (KOEO) = total voltage drop in either the power or ground circuit should never exceed 100 mV (see Figures 6–13 and 6–14)

Voltage-drop readings less than the maximum allowable specification indicate that all components and connections that make up the circuitry have resistance levels low enough to be acceptable. If an excessive voltage-drop reading is encountered, then, with one DVOM lead connected to the battery (KOEO), the other lead should be drawn back through the circuit toward the battery (according to the applicable electrical schematic) until the voltage-drop reading is reduced to acceptable levels. At this point, you know that the high resistance is located between the point in the circuit where the last unacceptable reading was taken and the point in the circuit where the first acceptable reading was taken.

When performing voltage-drop tests on circuits that power load components at the rear of the vehicle, a DVOM lead of extra length may be manufactured. With this long lead connected to the vehicle's battery using an alligator clip, the DVOM may now be carried to the rear of the vehicle to perform the voltage-drop tests. The wire gauge is not critical except for reasons of its durability because the DVOM's high internal resistance does not allow any substantial current flow through the meter when making voltage tests. This extra length lead should be plugged into the DVOM's positive jack and connected to battery positive when performing insulated side voltage-drop tests; it should be plugged into the DVOM's negative jack and connected to battery negative when performing ground-side voltage-drop tests.

Finally, concerning voltage-drop testing of computer circuits, consider each of the following statements:

- All automotive computers have internal logic gates that perform the decision-making function of the computer.
- Each logic gate must receive the 5-V reference voltage from the computer's voltage-reference regulator or decisions will be either faulty or nonexistent.
- The reference-voltage regulator must receive a minimum of 9.6 V (minimum voltage that is dropped across the computer itself) to produce the 5-V output signal to the sensors and logic gates.
- If battery voltage falls below 9.6 V, the logic gates cannot function correctly.
- If battery voltage is 12.6 V but excessive voltage drop exists in either the positive-side or negative-side circuitry of the computer so that the voltage drop across the computer itself is less than 9 V, the logic gates cannot function correctly.
- Therefore, when attempting to start an engine, as the operation of the starter motor pulls battery voltage low, it does not take an enormous amount of unwanted voltage drop in a computer power or ground circuit to keep a computer from functioning properly, resulting in the likely failure of a PCM to pulse a fuel injector or fire an ignition coil.

As a result, any time a computer seems to be functioning abnormally (or not at all), test the power and ground circuits for excessive voltage drop before deciding to replace the computer.

Using Voltage-Drop Tests to Identify Intermittent Problems within the Circuitry

It should be noted that voltage-drop testing can be used to identify excessive unwanted resistance in circuits that are experiencing *intermittent* symptoms, even when the symptoms do not appear to be present. This is because as circuit conditions change (cooling off, for example), the symptom may seem to disappear, but in fact the excessive resistance does not totally disappear. It only decreases to a value that allows the circuit to begin operating again. As a result, the excessive resistance can still be identified by a voltage-drop test, even with no apparent symptom present. The measured voltage drop will not be as excessive as when the symptom is present, but it will likely still be above the maximum specifications allowed.

Diagnostic & Service Tip

For certain kinds of measurements, voltage-drop tests are far more reliable than resistance tests. This is particularly true for low-resistance measurements, such as resistance through a starter circuit. It is quite difficult to accurately measure fractions of an ohm, but it is easy to measure fractions of a volt. In consequence, experienced mechanics use a voltage-drop test in preference to a direct resistance measurement in almost every case.

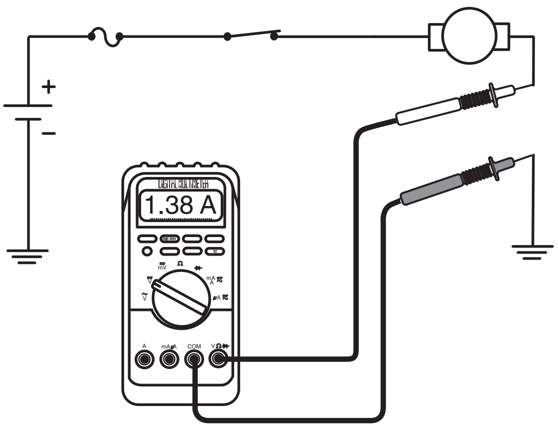


Figure 6–17 Ammeter connected in series as part of a circuit.

Measuring Amperage

An ammeter is used to measure the current flowing in a circuit. There are two types: the conventional type and the inductive type. The conventional type must be put in series as part of the circuit (Figure 6–17). The inductive type has an inductive clamp that clamps around a conductor in the circuit to be tested (Figure 6–18).

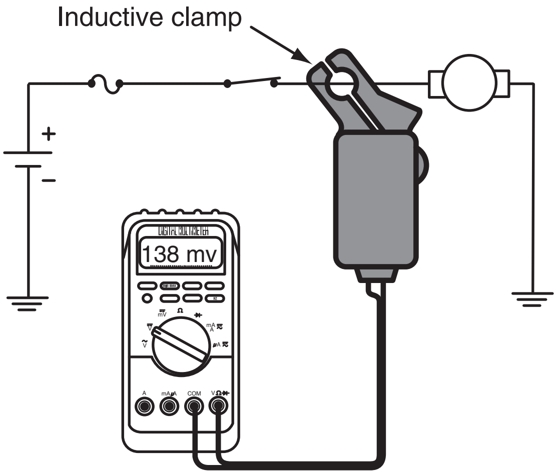


Figure 6–18 DVOM used with an amp clamp to perform a non-intrusive current draw test. If the output of the amp clamp is labeled as "1 mV/amp," the 138 mV reading equates to 138 amps.

The clamp contains a Hall effect device that uses the magnetic field around the conductor that it is clamped around to create an electrical signal. The strength of the signal depends on the strength of the magnetic field around the conductor, which in turn depends on the amount of current flowing through it. The DVOM displays a voltage reading that corresponds to the strength of the signal. The inductive ammeter is more convenient to use because it eliminates the need to open the circuit.

When using a conventional ammeter, it is important to select the correct scale. Passing 5 amp through an ammeter with a 2-amp scale selected can damage the meter. Most meters are fuse protected when on an amperage scale. Become familiar with an ammeter before attempting to use it.

Measuring Resistance

Resistance is measured with an *ohmmeter.* An ohmmeter is self-powered and has multiple scales that allow testing of resistance values from one-tenth of an ohm up to 20 MΩ (20,000,000 Ω). When manually scaling a DVOM on a resistance scale, it is good practice to begin on the uppermost scale and scale down until the over-range indicator is displayed, then scale back up one scale. If a good reading is obtained on the lowest scale, use the lowest scale to take the measurement.

Remember that an ohmmeter does have an internal voltage source and, therefore, should never be connected to a circuit or component that has power to it. If such a connection is made, the result could be anything from an inaccurate reading to a damaged meter. Also, because of the internal power source, do not ever connect an ohmmeter to a live airbag or airbag circuit on a supplemental restraint system (SRS)-equipped vehicle.

To help the reader understand how the resistance scales of a DVOM function, the following text describes how an analog ohmmeter functions. The DVOM accomplishes the same things, only using solid-state electronics to achieve them.

When an analog ohmmeter is turned on, its internal battery tries to pass current through the meter coil and the two leads, but unless the leads

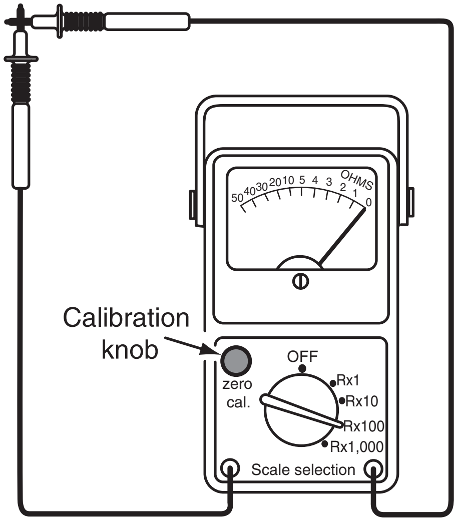


Figure 6–19 Calibrating an analog ohmmeter.

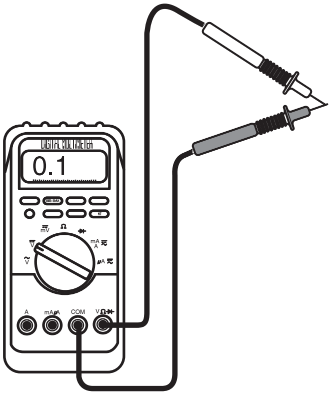


Figure 6–20 Testing the calibration of a DVOM's resistance scale.

are electrically connected together outside the meter, the circuit is open. If the two leads are touching or if they contact something that has continuity, the circuit is closed. If the leads are connected directly to each other, enough current should flow to cause the meter to swing full scale to the right, which represents zero ohms (Figure 6–19). If the leads are across a conductor, component, or part of a circuit, the resistance of that unit will reduce the current flow through the meter's circuit. The reduced current flow produces a weaker magnetic field, and the meter's needle will not be moved as far to the right. A digital ohmmeter has an electronic circuit that produces a digital readout in response to the amount of current flowing.

Most needle-type (analog) ohmmeters must be calibrated before each use. Calibration adjusts for voltage variation in the meter's battery due to the discharge that occurs during use. This is done by touching the leads together and adjusting the zero knob until the needle reads zero ohms (Figure 6–19). This establishes that the magnetic field produced by the current flowing through the meter's coil and external leads moves the needle to zero. Any additional resistance placed between the external leads will lower the current flow and will be displayed as the amount the needle lacks in reaching the zero line. Analog ohmmeters also must be recalibrated each time a different scale is selected because selecting a different scale changes the meter's internal resistance.

DVOMs do not have a zero adjust knob, but the leads should be shorted together while the DVOM is on the lowest resistance scale (Figure 6–20). If any value other than zero is displayed, this value should be subtracted from the displayed reading when making resistance measurements of low-resistance components (Figure 6–21). Some high-end DVOMs have

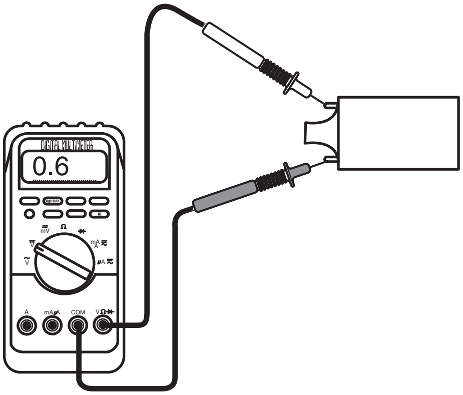


Figure 6–21 When using a DVOM to test the resistance of a low-resistance component, the resistance of the leads and meter should be subtracted from the displayed value.

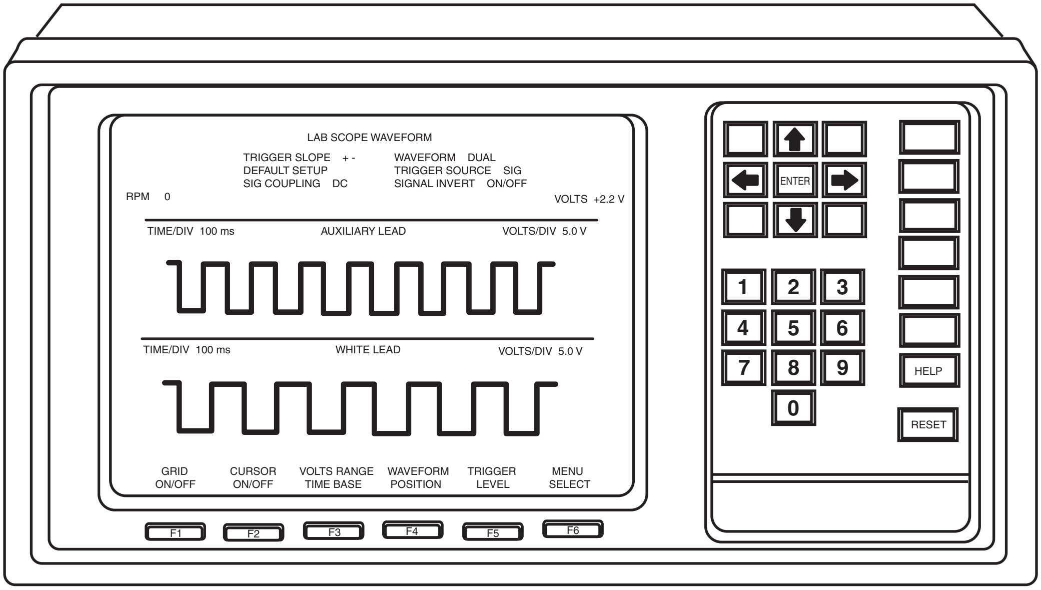


Figure 6–22 A multifunction, dual-trace lab scope.

a relative-resistance feature that allows the DVOM to automatically compensate for any resistance in the leads—simply touch the leads together and depress the "relative resistance" button. Remember to change the DVOM's internal battery regularly. Many DVOMs display a "low battery" indicator when the battery's charge becomes low.

Advantages

A DVOM is very easy to connect, read, and interpret. It provides an easy method for accurate pinpoint testing of most components or circuits. Again, you must be careful when interpreting the displayed reading.

Disadvantages and Limitations

A DVOM is unable to read "time" and may be ineffective in diagnosing certain component failures in which this is important—for example, an oxygen sensor's response time. If time is a critical measurement, then a DSO should be used.

DIGITAL STORAGE OSCILLOSCOPES

A DSO (also sometimes referred to as a *lab scope*) is one of the great forward leaps in diagnosing automotive computer systems. Similar in design to the analog bench-top oscilloscopes of the past that were used in the electronics field, these units also utilize computer-generated waveforms that can be frozen in time, measured, downloaded to a PC, and printed out. Figures 6–22, 6–23, 6–24, and 6–25 show typical DSOs or lab scopes. Graphing multimeters can also perform much the same function as a DSO.

Purpose and Functional Concept—Voltage and Current Waveforms

A DSO allows the technician to see a waveform of *voltage over time* (Figure 6–26) in order to allow accurate pinpoint testing of system faults associated with these voltage signals. It also allows evaluation of the characteristics associated with these voltage signals, such as frequency, duty-cycle on-time, and pulse-width on-time. A DSO

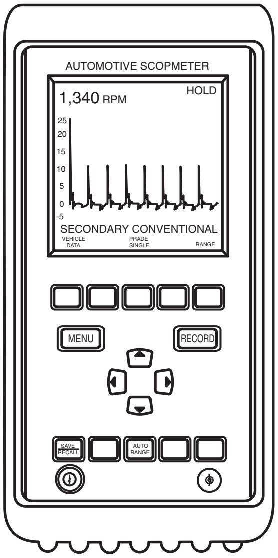


Figure 6–23 A typical DSO.

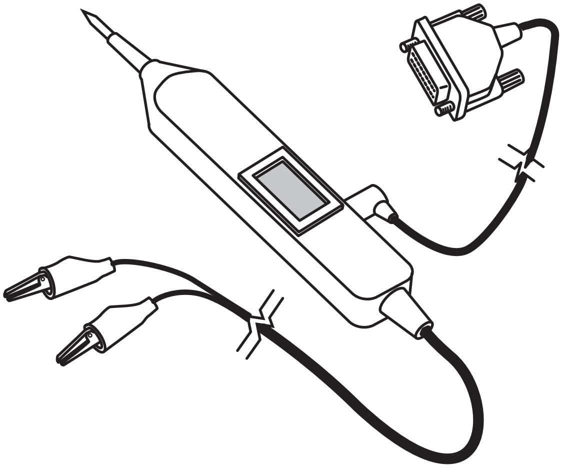


Figure 6–25 A probe scope (Wittig Technologies) can be used alone or the waveform can be downloaded to a desktop or laptop computer.

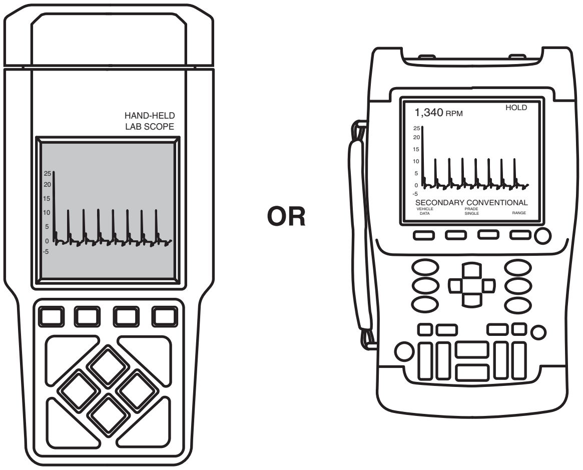


Figure 6–24 The modern handheld lab scope is powerful yet convenient to use.

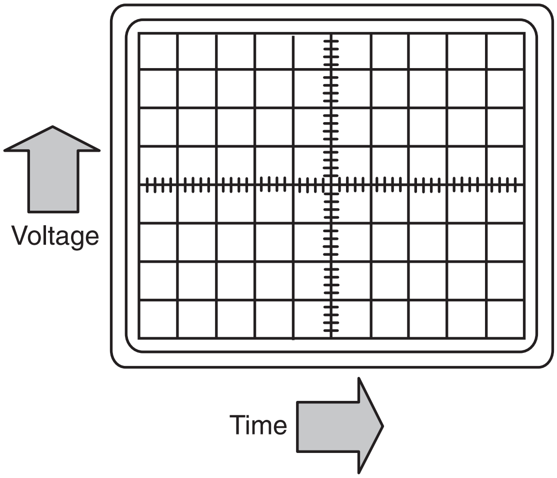


Figure 6–26 Typical DSO screen.

can also be adapted to display a waveform of *current over time* to allow the technician to consider a load component's current draw in diagnosis.

A DSO can provide in-depth information about the electrical characteristics of a circuit. Some DSOs provide multiple channel (trace) capability, allowing the technician to capture more than one waveform simultaneously (Figure 6–27). A DSO may have one-, two-, three-, or four-channel capability. It has one lead set for each channel. Multiple channels may share a common ground lead. The DSO screen is typically divided into eight voltage divisions and ten time divisions (Figure 6–26), though this can vary among manufacturers.

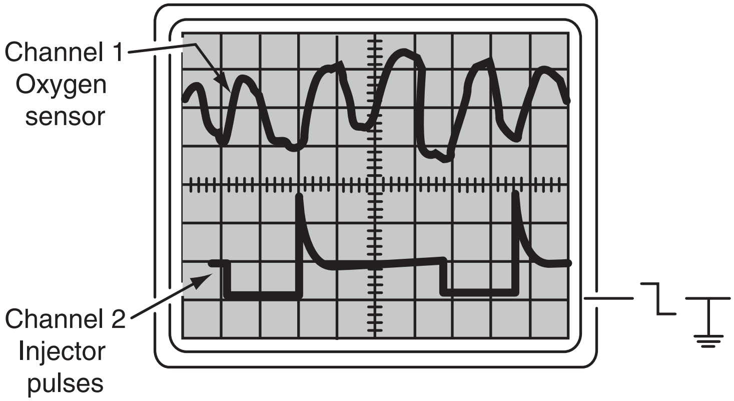


Figure 6–27 Lab scopes have two or more traces, so you can compare signals—for example, that of an oxygen sensor to that of injector pulse width.

Functional Procedure—Voltage Waveforms

A DSO has two leads per channel, one positive lead and one negative lead, making for an easy basic connection. Connect the leads to the DSO as indicated. Connect the negative probe to a clean, unpainted ground. Connect the positive probe to any voltage you wish to measure.

To adjust the DSO's characteristics to see a proper waveform, several adjustments need to be made. These include four initial adjustments and four **trigger** characteristics. While scope *"buttonology"* differs from one brand of scope to the next and from one model to the next, these eight adjustments apply to all lab scopes, whether of the digital variety (discussed here as a "DSO") or their analog counterparts. Any other adjustment concerns will pertain to the unique buttonology of the oscilloscope and will be covered in the owner's manual that comes with the scope when you purchase it.

The Four Initial Adjustments

Coupling. Adjust the coupling to the type of voltage signal you will be connected to—AC or DC.

Selecting the AC coupling instructs the scope that the voltage is to be equally displayed both above and below ground (the zero-volt line). If you connect the scope to a rapidly switched DC voltage when the AC coupling is selected, it will display as an AC voltage.

Selecting the DC coupling will actually allow the scope to display both DC and AC voltage signals. When the DC coupling is selected, a DC voltage signal will operate in a range from zero volts to a voltage above ground; an AC voltage signal will go both above and below ground.

Ground Level. Adjust the ground level (sometimes known as the *vertical waveform position*) to the middle of the screen to read an AC voltage and toward the bottom of the screen (ideally, one division from the bottom) to read a DC voltage.

Volts Per Division. Adjust the volts/division (or on some units, volts per screen) to allow you to see the entire amplitude (or range) of the voltage. Adjusting the volts/division to a value that is too small may cause your voltage to move off the visible screen and seemingly disappear. Adjusting it to a value that is too large will make the detail of the waveform more difficult to see.

Time Per Division. Adjust the time/division (or on some units, time per screen) to allow you to see two or three complete patterns of the waveform. Adjust this value *shorter* to see more *detail* of the waveform and *longer* to see more of the waveform's *trend.* For example, if you were testing an oxygen sensor's ability to produce proper voltage values on an operating engine for the sake of testing the sensor itself, you would ideally adjust this short enough to see more

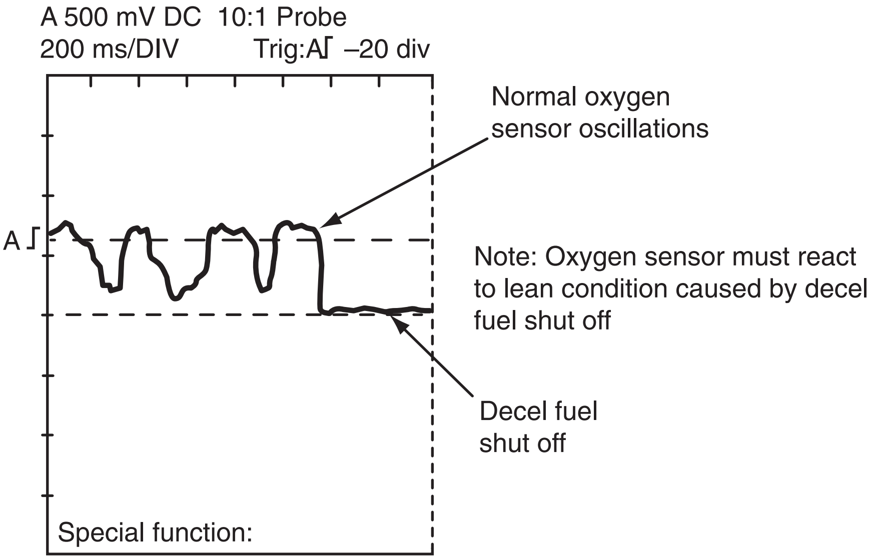


Figure 6–28 A lab scope allows you to see both the quantity and the quality of the signal, as with this O_2 sensor pattern.

detail—perhaps 100 milliseconds per division (ms/div). But if you then wanted to use the oxygen sensor's waveform to verify the ability of the engine computer to properly control the air/fuel ratio while driving the vehicle, you would ideally adjust this to see more of a trend—perhaps 1 s/div. Examples of both an oxygen sensor waveform and a mass air flow (MAF) sensor waveform are shown in Figures 6–28 and 6–29 with the time adjusted to 200 ms/div in both figures.

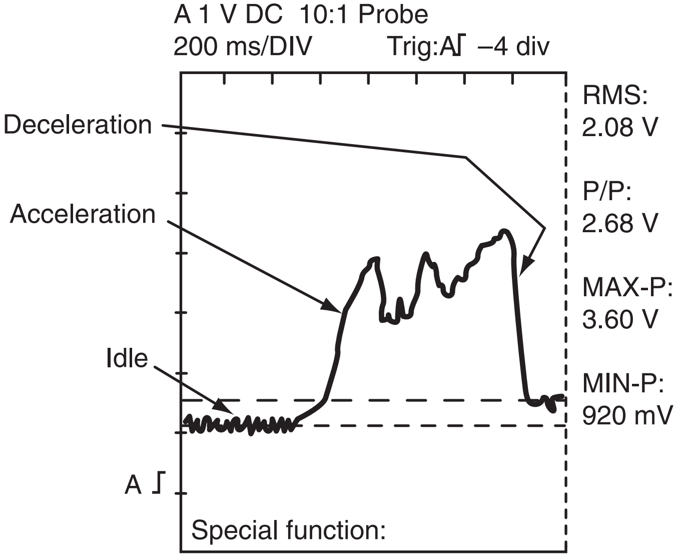


Figure 6–29 All the detail necessary to catch intermittent glitches and fast-occurring faults is present and controllable with a modern lab scope. This figure shows the voltage waveform of an analog MAF sensor.

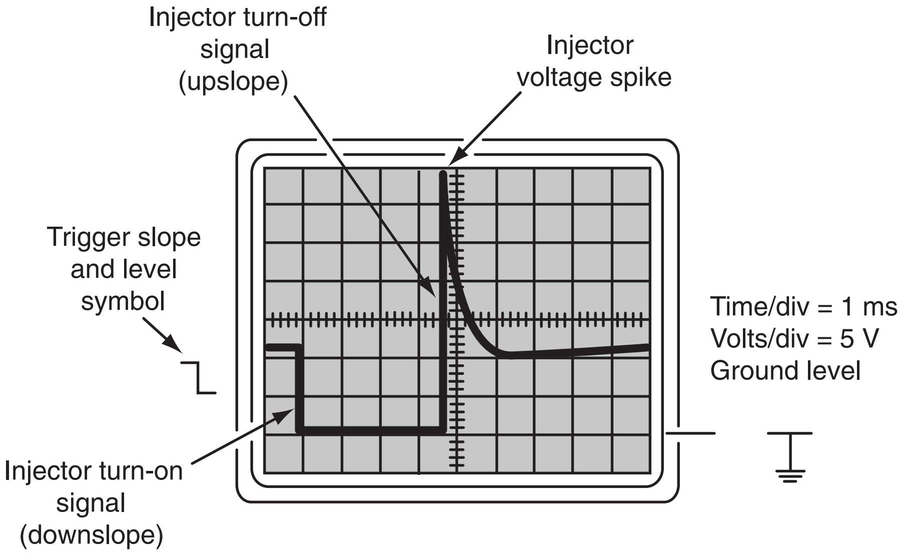

Injector turn-off signal (upslope)
Injector voltage spike
Trigger slope and level symbol
Time/div = 1 ms
Volts/div = 5 V
Ground level
Injector turn-on signal (downslope)

Figure 6–30 A typical fuel injector voltage waveform.

The Four Trigger Characteristics

The four trigger characteristics work together to determine the instant in time that the DSO begins to display a waveform. If the trigger characteristics are misadjusted, the DSO randomly guesses where to begin a waveform, resulting in a waveform that will likely appear to walk across the screen.

Trigger Delay. Trigger delay is also sometimes known as the horizontal waveform position. Adjust this to begin the trace at a particular point on the screen—typically one division from the left edge of the screen. If you adjust this too far to the left edge of the screen, you may not see the initial event. This is why many ignition scopes do not show the initial firing line for cylinder number one at the left edge of the screen.

Trigger Level. Trigger level is a selected voltage value. The DSO begins the trace as it sees the voltage waveform cross this value. Adjust the trigger level to a value that is more than the lowest voltage of the waveform and less than the highest voltage of the waveform. Other factors may help you to determine the proper trigger level as well; for example, you would not want to trigger off a fuel injector's voltage spike but rather to trigger off the turn-on signal (Figure 6–30).

Trigger Slope. Trigger slope is used to determine whether the DSO will begin the trace on a voltage shift from low to high (upslope) or high to low (downslope) as the waveform crosses the trigger level. Adjust this to begin the trace on either an upslope or a downslope according to what you want to see in the waveform. For example, on a fuel injector waveform you would normally want the trace to begin with the turning on of the injector, not the turning off. This is accomplished by selecting a downslope to begin the trace as the voltage is pulled low on a ground-side switched injector (Figure 6–30).

Trigger Source. Trigger source is used to determine which lead is used to signal the DSO that the trace should begin. In most cases the trigger source is set to the lead you are using to capture the waveform (also known as an *internal trigger*). This keeps the DSO connections simple; just one positive lead and one negative lead must be connected to the circuit. In certain cases you may want to use another lead (also known as an *external trigger*) to trigger the waveform rather than the one being used to capture the waveform. A common example of an oscilloscope that uses an external trigger is a secondary ignition oscilloscope. When using an ignition oscilloscope to capture the secondary waveform of an ignition system, the secondary coil lead captures the waveform for all cylinders. But the number one cylinder trigger lead instructs the scope as to which of the cylinders' waveforms to begin with on the display screen.

Functional Interpretation—Voltage Waveforms

When interpreting a voltage waveform, you should look at the following characteristics. Depending upon the type of component or circuit you are testing, some of these characteristics may be more important than others.

Amplitude. The amplitude is how high and low the voltage goes. For example, a voltage that does not fall all the way to ground when a ground-side switched fuel injector is turned on indicates that resistance is still in that circuit after the point where the DSO lead is connected to it. Or if, when scoping the waveform of a magnetic pickup coil in the distributor of a running engine, you notice that the amplitude varies with each rotation of the distributor at a *steady* engine RPM, worn bushings or a bent distributor shaft is indicated, due to a reluctor-to-pickup air gap that varies with each rotation.

Time. Time in the waveform is important with such things as digital pulse trains (variable frequency, duty cycle, and pulse width), O_2 sensor testing, and signals used to identify speed or RPM. For example, you can see in a DSO's waveform how long it takes for the O_2 sensor to respond to an air/fuel mixture change. This type of failure would indicate a "lazy" O_2 sensor and is difficult to identify without the use of a DSO.

Shape/Symmetry/Sequence of Events. Inspect the waveform for glitches that could cause an improper signal to the PCM—for example, a TPS signal that intermittently drops out. A DSO makes these types of faults much easier to identify.

Cursors. Horizontal and vertical cursors are provided on most DSOs to allow precise measurements of both voltage and time. The horizontal cursors are used to measure a voltage difference; the vertical cursors are used to measure a time difference. These differences may be indicated by the delta symbol (Δ). For example, ΔV equals delta volts, or the voltage difference between the positions of the two horizontal cursors, and ΔT equals delta time, or the time difference between the positions of the two vertical cursors. Some scopes may show these values as "dV" and "dT," respectively.

Current Ramping

Another diagnostic approach gaining popularity is the use of a DSO to look at a current waveform, rather than a voltage waveform. This procedure is known as **current ramping.** It allows the technician to identify problems with electromagnetic load components that cannot be identified through the use of voltage measurements or voltage waveforms. To do this, you must couple the DSO with a *quality,* low-current, inductive current (amp) probe.

Inductive current probes are often used with a DVOM to measure current non-intrusively in that they simply clamp around a wire. They are self-powered and convert the measured magnetic field strength around the wire (indicative of the level of current flow through the wire) to a DC voltage (usually millivolts). The DVOM is then set on a DC voltage scale to read the indicated current flow. An adjustment is provided on the current probe to zero out the value on the DVOM when the probe is not clamped around a wire or when the circuit is turned off.

Low-amp current probes are manufactured and distributed by many different tool manufacturers. On the high end is the Fluke 80i-110s AC/DC Current Clamp. A considerably less expensive, but very common, current probe is the PDI/PDA

CA-60 Current Probe. Some differences will be noted in the following text.

A current probe works much the same way when used with a DSO. After connecting the current probe to the DSO, rotate/push the "zero" dial/button on the current probe so as to zero the waveform on the DSO to ground level. This can be done prior to placing the probe around the wire of a load component's circuit. However, due to the magnetic influence of the vehicle, it is sometimes most accurate if it is zeroed after placing the probe around the wire, provided that the current flow is turned off in the circuit.

The Fluke 80i-110s current probe requires you to turn a dial to "zero" the probe. The PDI/PDA CA-60 only requires you to push a button to perform this function. While this may seem advantageous, too often the technician will push this button accidentally after it is connected around a wire with current flowing in the circuit. This will falsely lead the technician to believe that the average current flow equates to zero ampere. On the Fluke probe, you will not accidentally "zero" it. Snap-on's equivalent current probe has a "zeroing" button like the PDI/PDA CA-60, but it is recessed, thus reducing the likelihood of an accidental "zeroing."

The probe may be placed around either the positive wire or the negative wire, since current flow is consistent throughout a series circuit. It should also be placed as close to the load component as possible to avoid picking up current for multiple load components. Current ramping is not recommended for input sensor circuits as these circuits usually have high resistance, resulting in very low current levels. Input sensors rely primarily on voltage values to communicate their information to the PCM.

Once the current probe is clamped around a wire and "zeroed," the circuit should be energized. If the current waveform appears upside-down, or is down below the lower edge of the DSO's visible screen, the current probe needs to be flipped. The Fluke 80i–110s has a polarity indicator on the nose of the probe. The PDI/PDA has no polarity indicator, so if you have one of these units you can label it yourself using a label maker. Once you have a current waveform, the same adjustments already discussed in "Digital Storage Oscilloscopes" should then be performed to obtain the optimum waveform on the visible screen of the DSO.

Most low-amp current probes have an adjustment that determines the millivolts-to-amps relationship. For the current probe's "Output," the Fluke 80i–110s give you the choice of either "10 mV/A" or "100 mV/A." The "100 mV/A" is the more sensitive scale; it enables you to adjust the DSO's volts/division to a less sensitive scale, thus reducing the sensitivity of the DSO to other "noise" on the waveform. The PDI/PDA CA-60 current probe is scaled differently: "1 mV/100 mA" and "1 mV/10 mA." Because you need to know how many millivolts represent 1 amp on the DSO screen, it is recommended to re-label the scales on the PDI/PDA CA-60 using a label maker, as follows: The "1 mV/100 mA" scale should be re-labeled to read "10 mV/A" and the "1 mV/10 mA" scale should be re-labeled to read "100 mV/A."

Once you have set the probe's scale and have set your volts per division on the DSO, you can calculate the amps per division on the scope. The formula for calculating amps per division is: millivolts per division at the DSO divided by how many millivolts represent 1 amp at the current probe. For example, if the DSO is set to 200 mV/div and the current probe's output is set to 100 mV/A, the DSO's waveform would represent 2 amp per division (200 divided by 100).

Current Ramping a Switched Device. A current waveform of a switched device such as a primary ignition coil winding, a solenoid's winding (a fuel injector, for example), or a relay's winding can show whether the winding is shorted.

When a circuit's switch is turned on, the current waveform *ramps upward* until it is fully saturated; hence the term *current ramping.* However, when the circuit's switch is turned off, this action forces all electron flow in the circuit to stop almost immediately. This concept can be illustrated by a water pipe with water flowing in it and a valve which can be quickly snapped open or closed. If

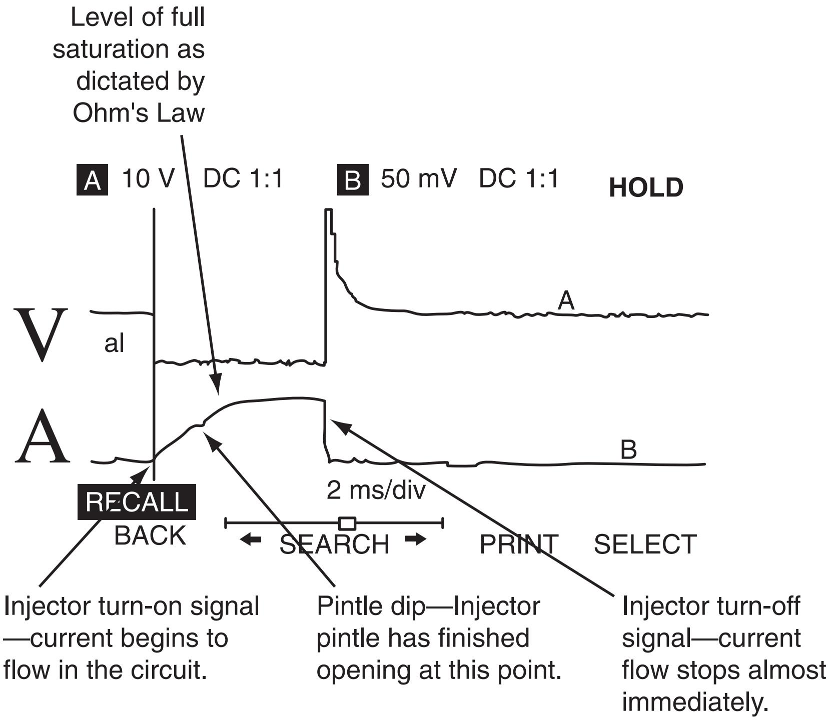


Figure 6–31 Voltage and current (amperage) waveforms for a standard fuel injector.

the valve is already open with water flowing in the pipe, and then the valve is suddenly snapped closed, the valve itself will physically and forcibly stop the flow of the water. But the reverse is not true. If the water valve is already closed and you suddenly snap it open, the valve will not physically start the flow of water; rather, the open valve simply allows the water pressure that is present to begin pushing water molecules again.

So it is with an electrical circuit—when the transistor (driver) that controls the circuit is switched on, it only allows the voltage to begin pushing electrons again, so that the level of current flow ramps upward relatively slowly; but when a transistor is turned off, current flow drops to zero ampere very quickly. This is why the turning on of a circuit never produces a voltage spike—the relative motion of the expanding magnetic field to the winding happens too slowly. This also explains why a voltage spike is potentially produced when the current flow is switched off—the current flow stops so quickly that the collapsing magnetic field cuts across the winding quickly enough to induce a voltage spike in the winding of the opposite polarity of the original voltage. Of course, when the circuit is turned on and the current is ramping upward, Ohm's law dictates the level of full saturation.

Figure 6–31 shows a typical voltage waveform and current waveform of a standard fuel injector. When the driver is turned on, the voltage is pulled to ground. It is at this point that the current begins to ramp upward. Then, when the driver is turned off, the current waveform shows a sharp downward line. It is at this point that a voltage spike appears in the voltage waveform.

When using a current waveform to test the primary winding of an ignition coil (Figure 6–32) or the winding of a solenoid such as a fuel injector (Figure 6–33), current that builds too

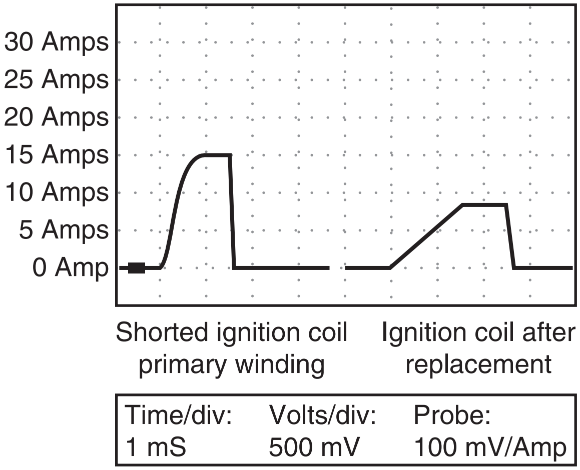


Figure 6–32 Ignition coil primary winding current waveforms, both before and after replacement.

quickly indicates that the windings are shorted; this is because the electrons did not have to overcome as much electrical resistance due to multiple coils of wire being shorted together. In most cases, shorted windings not only cause the current to build too quickly, but also to build too high, except in some ignition circuits in which the ignition module or PCM artificially limits the amount of current allowed in the circuit so as to keep a low-resistance coil primary winding from destroying itself.

The Ohmmeter versus Current Ramping. When using an ohmmeter to test a high-energy ignition coil's primary winding for shorts, a good winding may have a resistance of about 0.5 Ω. So if your ohmmeter reads 0.4 Ω, is the winding shorted? And how much of the resistance is in the leads? Actually, high-energy ignition coil primary windings are difficult to diagnose accurately with an ohmmeter due to their ultra-low resistance specifications. But capturing a current waveform of an ignition coil's primary winding can be extremely helpful in determining whether the winding is shorted or not.

Also, note the coil-on-plug schematic in Figure 6–34. As is typical of many such coil-on-plug applications, the driver (transistor) is physically located within the ignition coil assembly. While you could get a voltage waveform of the digital signal that controls the driver, it would be impossible to

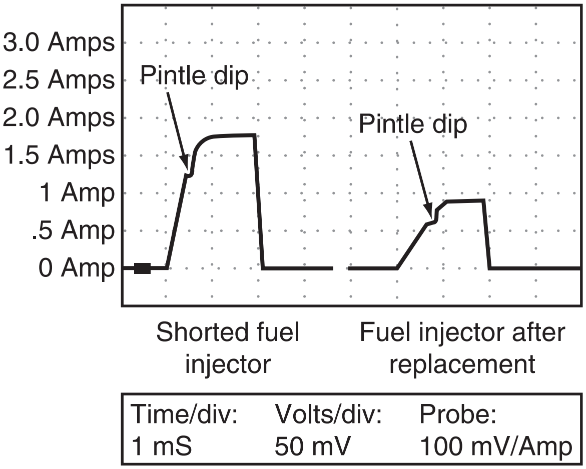


Figure 6–33 Standard fuel injector current waveforms, both before and after replacement.

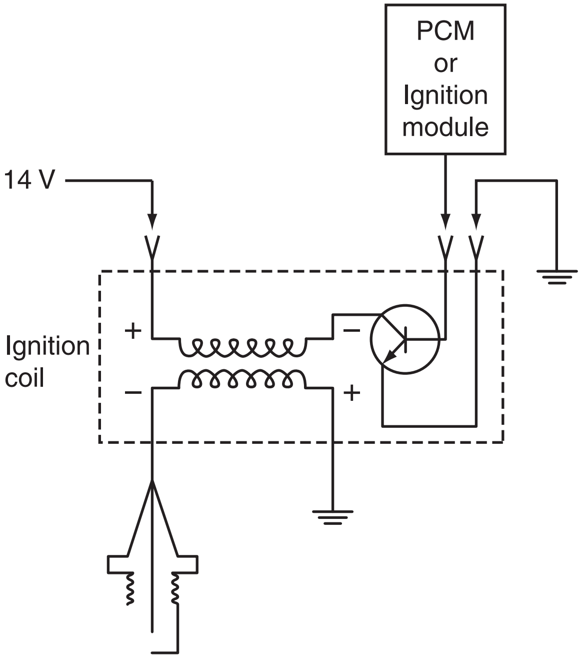


Figure 6–34 Electrical schematic of a typical ignition coil used in a coil-on-plug ignition system.

capture a voltage waveform of the primary winding being switched on and off by the driver. Your DSO voltage lead would have to connect to the ground side (switched side) of the primary winding between the winding and the transistor—this is not possible without cutting the coil assembly physically open and thus destroying the coil. And, likewise, in order to use an ohmmeter to test the resistance of the primary winding, you would have to cut the coil physically open in order to test the resistance across the winding itself without testing the resistance across the driver. Therefore, it becomes impossible to test the resistance of this type of primary winding when a shorted primary winding is suspected.

Because current is consistent throughout a series circuit, a current waveform can be captured by placing the current probe around either the positive wire or the negative wire—both methods provide identical waveforms. In this case, when you are unable to access the negative side of the winding, a current probe placed around the positive wire before it enters the coil assembly will provide you with a current waveform of the primary winding. Thus, current waveforms provide you with a way to check for a shorted primary winding in this type of ignition coil without cutting the coil open.

On the other hand, a fuel injector can usually be tested accurately for a shorted winding with an ohmmeter. If the resistance specification for an injector is 14 Ω to 17 Ω and your DVOM measures the resistance at 6 Ω, the injector's winding is obviously shorted. But using a current waveform as a diagnostic tool can still make the job easier. In order to use an ohmmeter to measure the injector's resistance, you must disconnect and isolate the injector's circuit. If performed at the injector, this can also involve attempting to get both DVOM leads on the injector's terminals simultaneously. To capture a current waveform of the injector, you need only place the current probe around either the positive or negative wire that conducts current flow to or from the injector. Your connection point can be some distance from the injector if the injector is physically difficult to access. Furthermore, no intrusive back-probing of a connector is needed in order to capture a current waveform, thus reducing the chance for damaging or compromising the circuit.

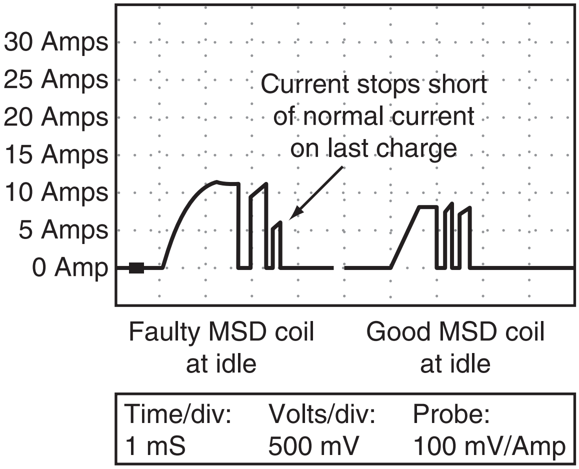


Figure 6–35 Current waveforms of both a faulty ignition coil and a good ignition coil in a Ford COP EDIS ignition system when the engine is at idle.

One final point to note concerning ignition coils: Some coil-on-plug ignition systems use a multiple spark discharge (MSD) when the engine is at idle to reduce excessive unburned hydrocarbons caused by premature quenching of the flame front. These coils have been problematic on some applications, but current waveforms can quickly identify faulty coils (Figure 6–35). Simply compare the current waveforms of each of the separate ignition coils with the engine at idle. Expect these coils to fire just once when the engine RPM is raised from idle.

Current Ramping a Motor. When using current ramping to test a motor, such as a cooling fan motor or a fuel pump motor, the current waveform can tell you quite a lot about the motor's condition. Each time a pair of commutator segments line up with the brushes, the current momentarily rises. As the commutator segments slip away from the brushes, the current momentarily falls until the next pair of commutator segments begins to line up. Most electric fuel pumps

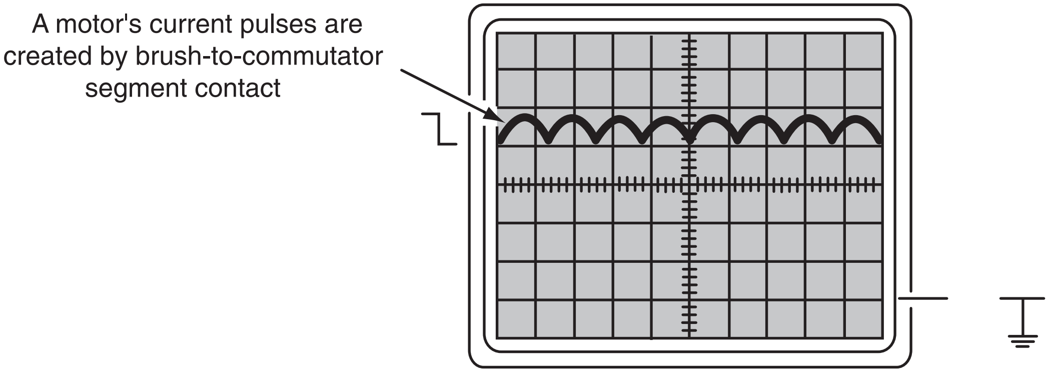

A motor's current pulses are created by brush-to-commutator segment contact

Figure 6–36 A typical DC motor current waveform.

contain either four or five windings, resulting in either 8 or 10 commutator segments (respectively) for each full rotation. You can even calculate the motor's RPM by looking at the frequency of the commutator pulses. See Figure 6–36 for a typical current waveform of a fuel pump motor.

When capturing the current waveform of a motor, consider that the level of current flow is dictated by two things: electrical resistance and mechanical resistance. Of course, electrical resistance affects current flow according to the principles of Ohm's law. To demonstrate the effects of mechanical resistance, take a blower motor without the cage on the shaft and power it up using jumper wires. Then, while watching the current waveform on a scope, use a shop rag to physically grab the spinning shaft and forcibly slow it down. (Do not attempt to do this without a shop rag as the spinning shaft will burn your fingers!) As you do so, the level of current draw increases. Thus, increasing mechanical resistance increases the current draw of a motor.

In summary:

- A motor's current flow that is excessively high can be caused by either:
  - o electrical resistance that is too low (shorted windings within the motor)
  - o mechanical resistance that is too high
- A motor's current flow that is too low can be caused by either:
  - o electrical resistance that is too high (poor brush-to-armature contact within the motor or excessive voltage drop within the circuitry)
  - o mechanical resistance that is too low

When a motor's circuit is first energized, expect to see a sudden upward spike in the current which will then settle down to a normal current value as the motor's armature starts rotating (Figure 6–37). This is normal and is due to the fact that the motor's armature is not moving when the circuit is first energized, thus constituting high

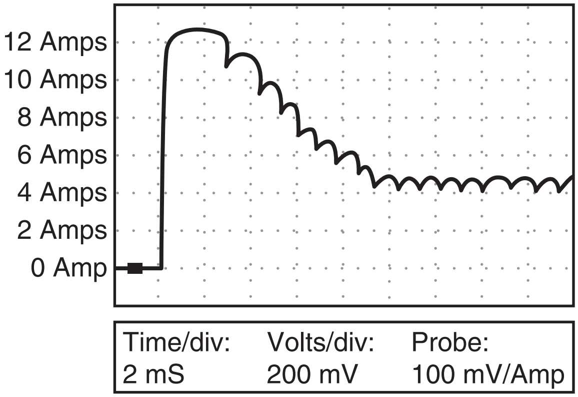


Figure 6–37 Fuel pump motor start-up in-rush current.

mechanical resistance initially. This is known as **motor start-up in-rush current.**

A motor's speed can also be checked with a current waveform. For example, if you can verify by using the scope's cursors that one rotation of the motor is occurring in 10 ms, multiply this by 100 (10 ms is 1/100th of a second) to determine that it is rotating at 100 rotations per second. Then multiply this by seconds to determine that the speed is 6000 RPM. Sometimes a motor that is operating at a slower speed than normal can be a clue as to what type of problem is present.

One huge advantage of current ramping a motor is that you are able to see faults within the motor assembly even before any symptoms have been experienced, indicating likely failure in the near future. Current waveforms are also, therefore, a great method to identify causes of intermittent symptoms due to poor motor condition. While any motor may be tested using current waveforms, fuel pump motors are the most critical in that their failure could potentially leave the vehicle totally stranded. Cooling fan motors follow in importance.

Some types of faults that may be demonstrated with a motor are as follows:

- Varying current draw due to varying mechanical resistance within the motor, caused by worn bushings (Figures 6–38 and 6–39).

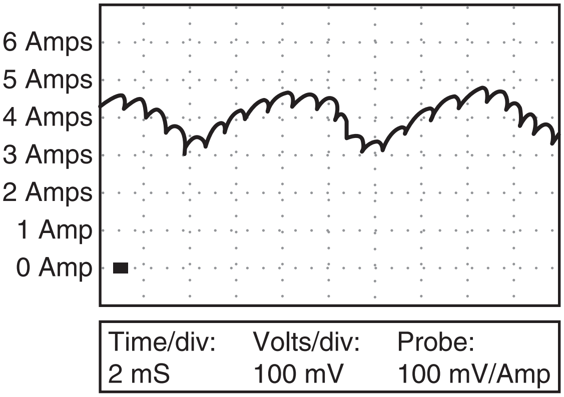


Figure 6–38 Varying current draw due to varying mechanical resistance within a motor caused by worn bushings.

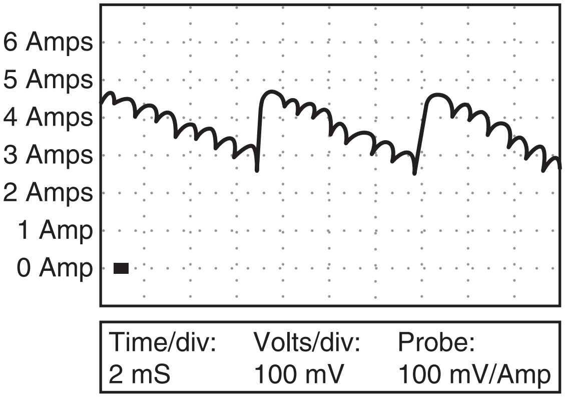


Figure 6–39 Varying current draw due to varying mechanical resistance within a motor caused by worn bushings.

- A current waveform that consistently drops to ground (zero ampere) twice per rotation indicates an open winding (Figure 6–40).
- Poorly defined shape of the waveform caused by brush wear (Figure 6–41). As the brushes wear, their carbon material is deposited on the armature segments decreasing the current flow, but it is also deposited between the armature segments, increasing the current flow when it should be further decreased. Ultimately, the high and low current peaks appear to be "clipped."

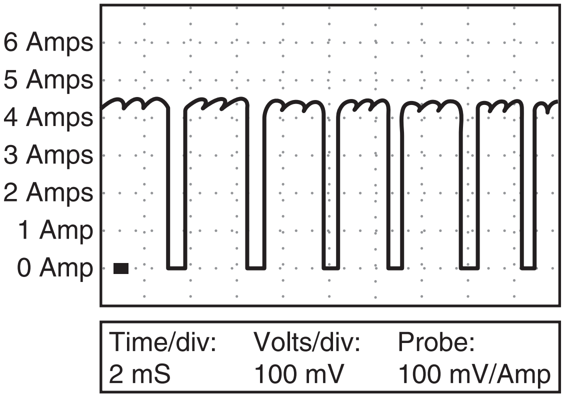


Figure 6–40 An open winding within a motor.

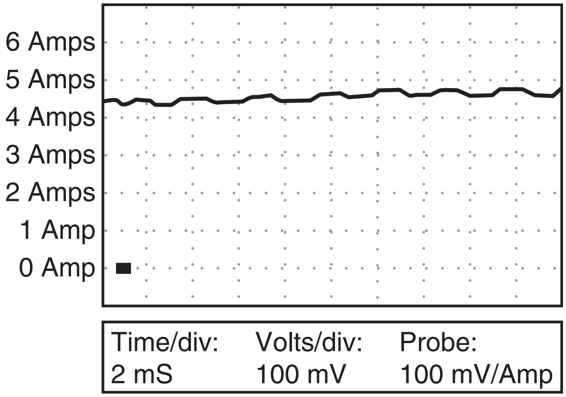


Figure 6–41 A poorly defined shape of a motor's current waveform indicates brush wear.

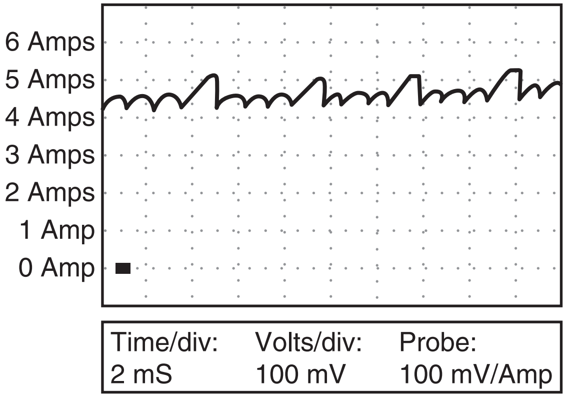


Figure 6–43 A shorted winding within a motor.

- Noise on the waveform or intermittent dropping to ground (zero ampere) indicates poor electrical contact between the brushes and the commutator segments (Figure 6–42). This cannot be an open winding if the armature is seen to rotate more than 180 degrees at any time without dropping to ground.
- Shorted windings where the current for one winding seems to rise above the rest (Figure 6–43).
- Any combination of the above (Figure 6–44).

Each of these conditions can be responsible for *intermittent* symptoms, particularly those such as "the vehicle stalls on a hot day until it cools down for 20 to 30 minutes." Current ramping can allow you to diagnose intermittent problems with motors more effectively than any other method. With this type of symptom, for example, the technician might capture a current waveform of the fuel pump.

Remember that an electric fuel pump assembly consists of about 90 percent electric motor and 10 percent mechanical pump driven by the motor. If you have a complaint of "stalling on a hot day until cool-down is achieved" and you verify a loss of fuel pressure at a time when the engine is stalled, capture the fuel pump's current

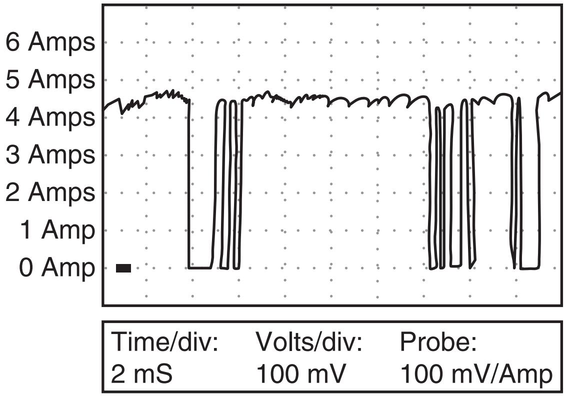


Figure 6–42 Poor brush-to-armature contact within a motor.

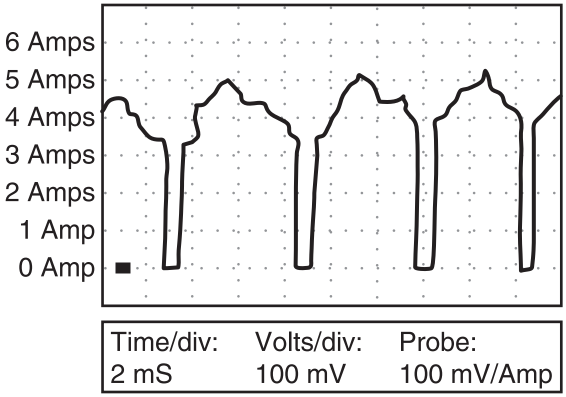


Figure 6–44 A motor with an open winding, a shorted winding, and worn brushes.

waveforms, both when the engine is running and when the engine is stalled. If the waveforms appear okay in terms of everything previously discussed, this only proves that the fuel pump's electric motor is in good condition. Compare closely the level of current draw with the engine running and with the engine stalled. If the current draw of the fuel pump is reduced by about 1½ amp when the engine is stalled compared to when the engine is running, suspect that the high heat conditions are causing the armature's shaft to slip in the pump's drive gear due to the expansion of dissimilar metals when the unit is hot. This will cause a total loss of fuel pressure, even though the lab scope's current waveform shows that the pump's motor is still rotating. Usually, in this event, the amount of fuel pump noise that is heard at the fuel tank's neck is also reduced when the engine is stalled. The speed of the fuel pump, as indicated in the current waveforms, may not necessarily be increased due to the inductance properties of the motor's magnetic field.

Current waveforms of electric cooling fans may also be captured to aid in diagnosis. These look extremely similar to fuel pump current waveforms. You may also capture a current waveform for other motors as well, including wiper motors and starter motors (for a starter motor, use a high-amp current probe connected to the lab scope). But, because mechanical resistance affects current draw, expect these current waveforms to look extremely uneven, as the wiper motor must allow the wipers to physically stop on the windshield and then get them moving again and a starter motor is affected by the compression pulses of the cylinders. That makes diagnosis using current waveforms of these motors somewhat more challenging. Even so, such things as open windings may be seen easily.

DSO Waveforms, Data Bases, and Your Customers

When you have captured a current waveform of a fuel pump that has an open winding (for example), save this waveform to the scope's memory and then download it to a PC. Create a file folder system for "Voltage Waveforms" and another for "Current Waveforms." Under each of these folders, create a folder for each automobile manufacturer ("GM," "Ford," and so on). Within each of these, create a folder for various components or other tests, and within each of these create folders for both known bad and known good waveforms. Then put your defective fuel pump waveform in the appropriate folder. After replacement of the part, be sure to capture and download a waveform of the new fuel pump to the appropriate folder. In this manner, you can begin to create your own database. Be sure to back up your database regularly to a second hard drive, a flash drive, a CD-ROM, or a DVD-R, DVD+R, or DVD RAM disk.

Also, by downloading a waveform to your PC, you can now print out "before and after replacement" voltage and current waveforms. Staple these to the repair order.

One word of caution: Just because you have identified an open winding in the fuel pump of a vehicle that is experiencing "intermittent stall" symptoms, don't ever assume that this is the only problem that could cause this symptom. For example, this symptom can also be caused by an ignition module that has outlived its usefulness. However, if you present your printed waveform of the open winding to the customer, you have given him/her justification for spending their hard-earned money. If replacing the fuel pump does not ultimately solve the symptom, you still will have made a needed repair that could potentially have left them stranded in the near future.

Advantages

The advantages of a DSO are that it can allow you to perform pinpoint tests of the components and circuits in a computer system more effectively than any other means available. Voltage and current waveform databases are becoming more readily available. Also, you can build your own current waveform database by recording current waveforms of both good and defective load components (before and after repair waveforms) and then downloading these waveforms to a personal computer. As with any other testing technique, as you practice using a DSO, you will find that you become increasingly proficient with it and will wonder how you ever did without it.

Disadvantages and Limitations

When a lab scope function is built into a "big box" type of ignition scope, it does not lend itself to procedures such as verifying oxygen sensor waveforms while driving the vehicle under realistic load conditions unless you also have access to a dynamometer in the shop. Also, as a rule, the "big box" versions are not as adjustable as their portable counterparts. Even the more portable versions are typically larger than a DVOM, so you may want to use a standard DVOM for many tests due to its smaller size, even though most DSOs have a DVOM function built into them.

SAFETY CONSIDERATIONS WHEN USING A DVOM OR DSO

When using a DVOM or DSO to test voltage, today's technician must bear in mind several considerations. These considerations concern things to be aware of when purchasing test equipment and even the proper fuse to use when replacing a blown fuse in a DVOM.

Electrical Test Equipment for Safely Measuring High Voltages

Some of the concerns that have brought safety issues to the forefront are the vehicles that are now being produced. Vehicles with 42-V systems were introduced in the 2004 model year, and hybrids with working voltages from 144 to 650 V are being produced by several manufacturers. While there are many other concerns when it comes to measuring high voltages safely, the following information concerns what the technician should be familiar with regarding electrical test equipment.

UL/CSA Listing. To begin, when purchasing a DVOM or DSO, look specifically for the following identifications: "UL Listed" indicates that the test equipment is listed by Underwriters Laboratories, and "CSA Listed" indicates that the test equipment is listed by the Canadian Standards Association. Make sure that the UL and/or CSA symbols appear on the test equipment, not simply a statement that says "Meets UL/CSA standards."

Voltage and Category Ratings. When purchasing a DVOM or DSO, take note of the voltage and category ratings that are found on the unit. Even the leads should be labeled with the voltage and category for which they are rated. The International Electrotechnical Commission (IEC) sets these standards as used by the UL and CSA listing agencies.

The voltage rating is considered the highest voltage that the unit (or leads) can be used to safely measure continuously. Typical voltage ratings found on quality DVOMs and DSOs, as well as their leads, are either 600 V or 1000 V.

Category ratings have to do with the highest transient voltage (momentarily induced voltage spike) that the test equipment can safely withstand without damage. This could be anything from a voltage spike induced by switching of high-voltage equipment to a lightning strike. Keep in mind that high-voltage transient spikes are dampened by long lengths of wire and/or fuse protection. There are four assigned categories:

1. Category IV test equipment is designed to be used safely on the power lines that bring power to your home or office building.
2. Category III test equipment can be used safely on power distribution boxes and permanent installations such as central air conditioning units.
3. Category II test equipment can be used safely on fuse/circuit breaker–protected wiring within the walls of a home or office building.

4. Category I test equipment can be used safely on fuse-protected electronic devices that are connected to wall outlets.

Fuse Replacement. Many higher-end pieces of test equipment use fuses that are sand-filled. The reason for this is that a voltage above 20 V can sustain an arc following a short, even when an air gap is produced. If you replace such a fuse with an inexpensive fuse that does not contain the sand and then make a mistake with a 42-V system (for example, your leads are plugged into the DVOM to measure current and you connect the meter between battery positive and negative as if to measure voltage), the fuse would likely burn open, but current would continue to flow across the fuse's air gap and through the meter, thus destroying the DVOM. Therefore, always use the manufacturer's recommended fuse when replacing a burned fuse.

GAS ANALYZERS

Gas analysis and gas analyzers are more fully explained in Chapter 7 because a full chapter must be devoted to this topic. But in the context of the current chapter, the use of a gas analyzer is designed to quickly direct the technician to a problem area. That is, gas analysis is not in itself a pinpoint test procedure but instead can quickly direct the technician to problem areas where pinpoint testing should begin.

SUMMARY

This chapter outlined many pieces of diagnostic equipment, along with the advantages and limitations of each. It is designed to give the technician an overall view of when to use each piece of equipment, what types of tests can be performed with each piece of equipment, and what the test results mean to the technician. This chapter also differentiated between diagnostic equipment designed to lead the technician to the general area of a fault quickly, such as a scan tool or gas analyzer, and equipment suitable for making pinpoint tests of a circuit, such as a DVOM or DSO, whether used alone or in conjunction with a BOB.

▲ DIAGNOSTIC EXERCISES

1. A fuel injected engine does start and run. But after connecting a scan tool to the DLC of this vehicle and entering the requested data, a technician finds that after the ignition is switched on, the scan tool displays a message indicating "No communication." What types of problems could cause this?
2. After connecting a DSO to an electrical circuit in the engine compartment of a vehicle, a technician discovers that there is no visible trace on the screen. What types of problems could cause this?

Review Questions

1. Which of the following diagnostic tools is designed to help the technician quickly identify the area of a fault?
   A. A scan tool
   B. A DVOM
   C. A DSO
   D. Both B and C
2. Which of the following diagnostic tools is designed to help the technician pinpoint test the exact fault?
   A. A scan tool
   B. A DVOM
   C. A DSO
   D. Both B and C
3. Which of the following diagnostic tools is designed to allow the technician to access the PCM's data stream through serial data (binary code) communication with the PCM?
   A. A scan tool
   B. A DVOM
   C. A DSO
   D. Both B and C

4. Which of the following diagnostic tools is designed to allow the technician to measure time, such as the response time of an oxygen sensor?
   A. A scan tool
   B. A DVOM
   C. A DSO
   D. Both B and C
5. Which of the following diagnostic tools is the best tool for helping the technician identify a quick, intermittent glitch such as what might occur in a throttle position sensor?
   A. A scan tool
   B. A DVOM
   C. A DSO
   D. A non-powered test light
6. Technician A says that if a scan tool says that the EGR valve is being commanded to open 50 percent, you can be assured that the valve is working properly and no further testing is necessary on the EGR valve. Technician B says that if a scan tool shows that the voltage for the ECT sensor is out of range, then you can be assured that the ECT sensor itself is at fault and no further pinpoint testing is necessary on the ECT sensor circuit. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
7. Which of the following statements regarding the use of a BOB is false?
   A. It connects between the PCM and the computer harness.
   B. Once properly connected, it allows you to access all computer circuits with a DVOM or DSO.
   C. It can be used to access such information in the PCM's memory as fuel trim data.
   D. It allows you to make pinpoint tests of all computer circuits from one central location without back-probing.
8. Which of the following pieces of diagnostic equipment is best suited for making exact voltage measurements when pinpoint testing an electronic circuit?
   A. Non-powered test light
   B. Logic probe
   C. High-impedance DVOM on a DC volts scale
   D. Scan tool
9. Which of the following pieces of diagnostic equipment can damage computer circuits if not used properly?
   A. Non-powered test light
   B. Logic probe
   C. High-impedance DVOM on a DC volts scale
   D. Scan tool
10. A technician is using a DVOM to measure the resistance of a secondary ignition wire. The DVOM is set to a 20-K ohm scale. The display shows 7.92. To which of the following does this number equate?
    A. 7.92 Ω
    B. 792 Ω
    C. 7920 Ω
    D. 158,400 Ω (7.92 × 20,000)
11. A technician is using a DVOM to measure the parasitic draw of a vehicle's electrical system on the battery. The DVOM is set to a 200-mA scale. The display shows 32. To which of the following does this number equate?
    A. 32 amp
    B. 3.2 amp
    C. 0.32 amp
    D. 0.032 amp
12. A technician has made voltage-drop tests on a PCM's power and ground circuits with the ignition switch turned on and the engine not running. The following results were obtained: Positive-side voltage drop = 0.068 V. Negative side voltage drop = 0.124 V. What is indicated?
    A. Both circuits are within specifications.
    B. The positive-side circuit is within specifications; the negative-side circuit has excessive resistance.

C. The positive-side circuit has excessive resistance; the negative-side circuit is within specifications.
D. Both circuits have excessive resistance.

13. A customer brings a vehicle into the shop and complains of intermittent stalling requiring a cool-down period before it will restart. During a road test the engine stalls. Testing shows that the fuel system has lost pressure and the fuel pump does not seem to run. After you get the vehicle back to the shop, you make voltage-drop tests of the fuel pump's power and ground circuits to test for the intermittent condition, and these tests prove that the circuitry is okay. What is the best test that can be performed to verify whether the fuel pump itself is responsible for the intermittent failure?
A. Perform a voltage-drop test across the fuel pump motor.
B. Use a DVOM to measure the average current that the fuel pump motor draws.
C. Use a DSO to look at the fuel pump circuit's voltage waveform.
D. Use a DSO and an inductive current probe to look at the fuel pump motor's current waveform.

14. A scan tool can provide all except which of the following?
A. Diagnostic trouble codes
B. Data stream information
C. Functional testing of the computer system
D. Pinpoint testing of the computer system

15. Technician A says that when adjusting the time per division on a DSO, adjusting this shorter allows the technician to see more detail of the waveform. Technician B says that when adjusting the time per division on a DSO, adjusting this longer allows the technician to see more of the waveform's trend. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

16. A DSO is properly connected to a circuit, but the waveform appears to be randomly "walking across the screen." Which of the following adjustments will most likely correct this condition?
A. Ground level
B. Volts per division
C. Time per division
D. Trigger characteristics

17. When looking at the current waveform of a fuel injector solenoid or an ignition coil primary winding, current that builds too quickly to the saturation level suggests what type of fault?
A. Open winding
B. Shorted winding
C. Circuit has excessive resistance on the insulated side
D. Circuit has excessive resistance on the ground side

18. When looking at a current waveform of a fuel pump motor, the waveform is seen to go to ground twice per each rotation of the motor. What does this indicate?
A. Open winding
B. Shorted winding
C. Physical binding due to worn bushings
D. Poor contact between the brushes and the commutator segments

19. When capturing a current waveform from a motor, what can higher than normal current draw indicate?
A. A motor that is binding mechanically
B. Shorted windings within the motor
C. High electrical resistance in the controlling circuit
D. Either A or B

20. When capturing a current waveform from a motor, what is indicated if the average current increases and decreases with each rotation of the motor?
A. An open winding
B. A shorted winding
C. Worn bushings
D. Current flow is reversing direction

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Chapter 7

Exhaust Gas Analysis

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Understand the theory of gas analysis.
- ☐ Describe the exhaust gasses measured by a gas analyzer.
- ☐ Recognize the methods used by gas analyzers to sample emission gasses.
- ☐ Understand how to use emission gas levels in diagnosing engine performance, fuel economy complaints, and emission failures.

KEY TERMS

Carbon Dioxide (CO_2)
Carbon Monoxide (CO)
Concentration Sampling
Constant Volume Sampling (CVS)
Exhaust Gas Analyzer
Grams per Mile (GPM)
Hydrocarbons (HC)
Nitrogen (N_2)
Oxides of Nitrogen (NO_x)
Oxygen (O_2)
Water (H_2O)

Understanding what produces each of the gasses that exit the tailpipe of an automobile is the basis for using these gasses to help in diagnosing symptoms of poor engine performance, poor fuel economy, and failure of emission tests. However, bear in mind that gas analysis is used in diagnosis to quickly narrow down the possible problem areas; gas analysis is not a pinpoint test in itself but, rather, must be followed up by the proper pinpoint tests. Gas analysis can be a very effective diagnostic tool when used properly—a complement to the other diagnostic tools available to today's technician.

THEORY OF GAS ANALYSIS

What Goes in Must Come out

When the engine is running, it is, in effect, operating as an air pump. Everything that comes into the combustion chamber through the intake valve is ultimately expelled in some form through the exhaust valve into the exhaust system. By measuring the gasses that exit the tailpipe, we can get a good idea of what happened in the combustion chamber. But first, a good understanding of how each of the gasses is formed is in order. Although several exhaust gasses are produced in minute amounts during combustion, the discussion here concerns the production of the primary exhaust gasses formed and their implications for the technician (Figure 7–1). An initial description of these gasses is also found in Chapter 2, but they are discussed in greater detail in this chapter.

To begin, both atmospheric air and fuel are introduced into the engine. Atmospheric air consists of about 78 percent **nitrogen (N_2)** and between 20 percent and 21 percent **oxygen (O_2).**

Fuel is made up primarily of **hydrocarbons (HC),** each molecule containing atoms of hydrogen and carbon. As the combustion within the cylinder

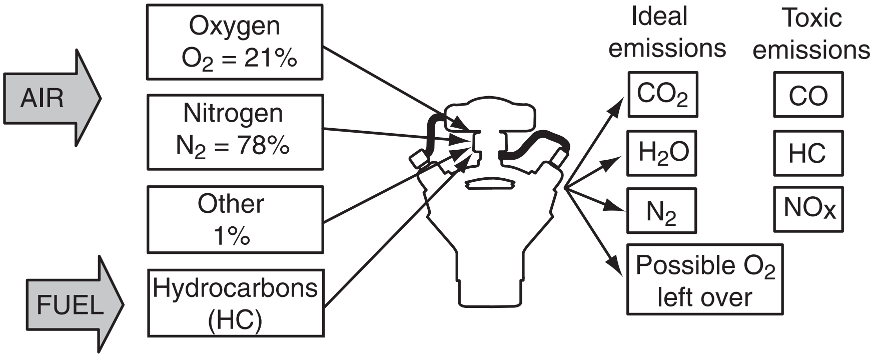


Figure 7–1 Exhaust gasses that result from combustion.

takes place, these components combine in a chemical reaction and then exit the cylinder.

Nontoxic Gasses

If an engine has good compression, ignition, and a stoichiometric air/fuel ratio, the combustion process will produce nontoxic gasses as follows. During combustion of the hydrocarbons, the carbon separates from the hydrogen. Both of these elements then recombine with oxygen. The hydrogen atoms combine with oxygen atoms to form molecules of **water** vapor or **H_2O,** with each molecule consisting of two hydrogen atoms and one oxygen atom. The carbon atoms combine with oxygen atoms to form molecules of **carbon dioxide** or **CO_2,** with each molecule containing one carbon atom and two oxygen atoms. Any nitrogen will, for the most part, go through the engine unchanged. And if the air/fuel ratio is slightly lean, a small amount of oxygen may be left over after combustion has taken place.

Toxic Gasses

Hydrocarbons. If some of the fuel does not burn during combustion, it exits the engine as unburned hydrocarbons (or HC molecules). If a *total misfire* occurs within the cylinder for any reason, HC levels will be *dramatically high.* This includes any misfire due to compression problems, ignition misfire, or a lean misfire, which occurs on a spark-ignition engine when a lean air/fuel ratio causes the fuel molecules to be spread so far apart that the flame front cannot propagate (about a 17:1 air/fuel ratio in most engines, even leaner in some other engines depending upon combustion chamber design). If the air/fuel ratio is too rich, there is not enough oxygen to burn all of the fuel completely. This is sometimes known as a *partial misfire* and results in *moderately high* HC levels.

The low surface temperature of a cylinder wall, which rapidly draws heat from the HC and O_2 molecules that are in contact with it, will prevent the flame front from reaching or maintaining ignition temperature. This causes premature quenching of the flame front and results in excessive HCs in the exhaust. This condition can be caused by low coolant level or low coolant temperature by reason of a stuck-open thermostat. It can also be a result of over-advanced ignition timing or simply the result of low engine speed such as idle. Some engine designs, particularly smaller engines, are more prone to producing excessive HCs at idle than others. Also, when an engine is first started on a cold day, the combustion chamber surfaces will all initially be too low to sustain clean emissions performance.

Carbon Monoxide. **Carbon monoxide (CO)** is *always* produced as a result of combustion taking place with a rich air/fuel ratio because of its shortage of oxygen. Misfires do not produce CO. For example, replacing the spark plugs or spark plug wires would not be an effective repair to correct high CO levels. Think of a CO molecule as a molecule that is starved for oxygen. Eventually it will seek out another oxygen atom and be converted to CO_2. In the meantime, if you inhale it, carbon monoxide can cause dizziness, nausea, and even death. You cannot detect the presence of CO in the air through sight, taste, or smell.

Oxides of Nitrogen. **Oxides of nitrogen (NO_x)** are produced by combining nitrogen and oxygen. Nitrogen combines easily with other elements when placed under enough heat and/or pressure. Remember that atmospheric air is made up primarily of nitrogen (78 percent) and oxygen (20 percent to 21 percent). NO_x is formed as a result of atmospheric air being placed under enough heat and pressure to cause the oxygen and nitrogen to combine. A NO_x molecule consists of one nitrogen atom combined with one to five oxygen atoms, the most common automotive NO_x emissions being formed by combining the nitrogen atom with just one or two oxygen atoms. When the nitrogen atom is combined with just one oxygen atom, nitric oxide (NO) is formed; NO makes up about 95 percent of automotive NO_x emissions. When the nitrogen atom is combined with two oxygen atoms, nitrogen dioxide (NO_2) is formed, making up less than 5 percent of automotive NO_x emissions. Both types of molecules are collectively referred to as oxides of nitrogen, or NO_x.

In an engine's combustion chamber, while small amounts of NO_x may begin to form at temperatures as low as 2000°F to 2100°F, generally NO_x formation does not become critical until about 2500°F and higher.

As a toxic emission, NO_x has been proven to have a direct negative effect on the human respiratory system. NO_x also reacts with moisture to produce low-level ozone and acid rain. Finally, while some forms of NO_x are colorless, nitrogen dioxide (NO_2) is seen as a reddish-brown layer over urban areas, generally associated with smog, when it is present in heavy concentrations.

MEASURED GASSES

Exhaust Gas Analyzers

Of the seven gasses previously defined (four nontoxic gasses [N_2, O_2, H_2O, and CO_2] and three toxic gasses [CO, HC, and NO_x]), up to five of them are generally measured, depending on the particular **exhaust gas analyzer.** Early gas analyzers only measured HC and CO emissions. Unfortunately, on a vehicle that has a catalytic converter in good working order that is up to proper operating temperature, HC and CO emissions may both be effectively oxidized within the converter. If the purpose is to perform an emission test, this does not present a problem. But if the purpose is to analyze the exhaust gasses to help diagnose engine performance problems, this reduction of HC and CO can give the impression that the engine is performing more efficiently than it really is.

Today's four-gas analyzers measure not only HC and CO but also CO_2 and O_2. Both CO_2 and O_2 are, of course, nontoxic gasses, but they are also valuable for analytical purposes if properly understood.

Modern five-gas analyzers also measure NO_x in addition to HC, CO, CO_2, and O_2. The additional capability to measure NO_x adds very little to our analytical abilities but is a necessary addition if you work in a geographical area where local emission laws require testing for NO_x.

How the Air/Fuel Ratio Affects the Performance of the Gasses

Effect of Air/Fuel Ratio on Hydrocarbons. Hydrocarbon levels will increase as a result of any misfire occurring within the cylinder for any reason. If the engine compression and ignition systems are in good working order and valve timing and spark timing are correct, HC levels will be low at a stoichiometric air/fuel ratio (14.7:1). As the air/fuel ratio moves richer from 14.7:1, HC levels increase moderately as the air needed for complete combustion is proportionately reduced

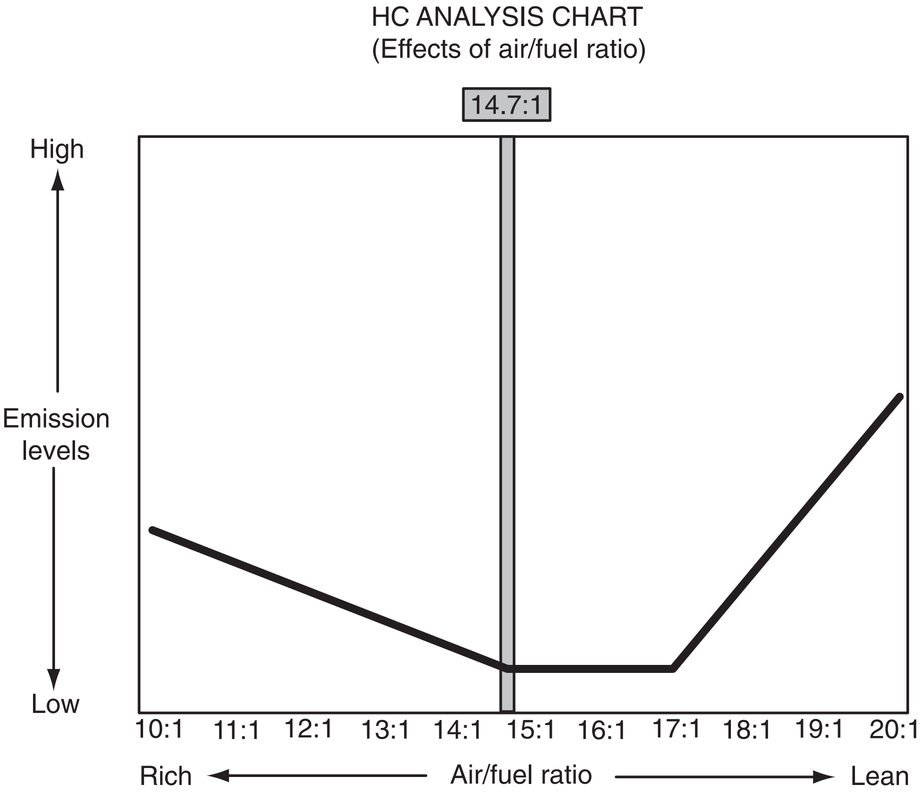


Figure 7–2 Effect of air/fuel ratio on hydrocarbons.

(Figure 7–2). As the air/fuel ratio moves leaner from 14.7:1, HC levels remain low until the point of lean misfire, about 17:1 for many engines. Beyond this point, they tend to increase dramatically.

Effect of Air/Fuel Ratio on Carbon Monoxide. Carbon monoxide levels are not increased because of engine misfire (in fact, they are slightly reduced). They are also low at a stoichiometric air/fuel ratio. As the air/fuel ratio moves richer from 14.7:1, CO levels increase as the air needed for complete combustion is reduced (Figure 7–3). As the air/fuel ratio moves leaner from 14.7:1, the CO level remains low. As a result, you can determine from CO levels how far rich of stoichiometric the air/ratio is (assuming the catalytic converter is not yet up to operating temperature), but CO levels cannot be used to determine how lean of stoichiometric the air/fuel ratio is.

Effect of Air/Fuel Ratio on Oxygen. Oxygen levels are slightly increased because of misfire (a misfire results in a failure to consume both the fuel and the oxygen). When misfire is not occurring, O_2 levels are low at stoichiometric but increase as the air/fuel ratio moves leaner from 14.7:1 due to increased levels of oxygen being "left over" after combustion (Figure 7–4). As the air/fuel ratio moves richer from 14.7:1, O_2 levels stay low. As a result, you can determine from O_2 levels how far lean of stoichiometric the air/ratio is, but O_2 levels cannot be used to determine how rich of stoichiometric the air/fuel ratio is. Of course, all of this assumes that no extra atmospheric air is getting into the exhaust system. Therefore, in contrast to performing an emission test, it is important for gas analysis purposes that any existing air injection system be disabled. Also,

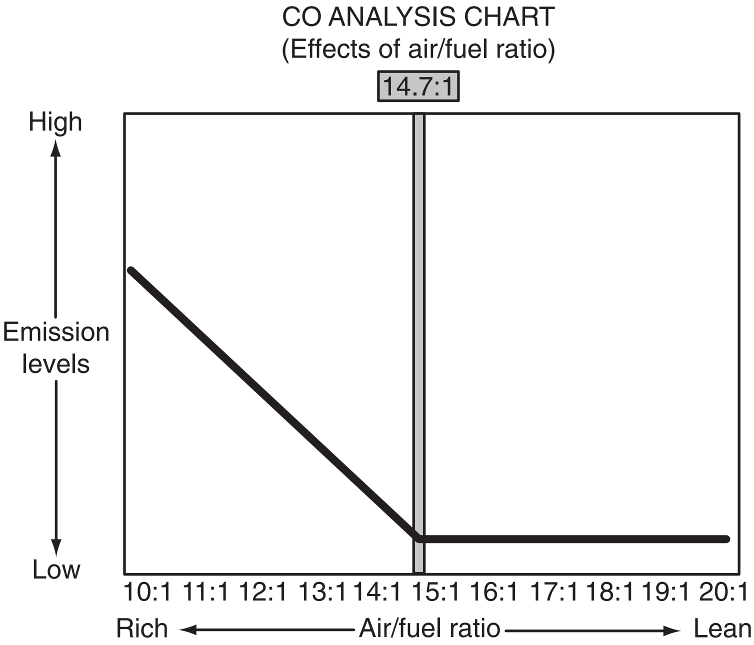


Figure 7–3 Effect of air/fuel ratio on carbon monoxide.

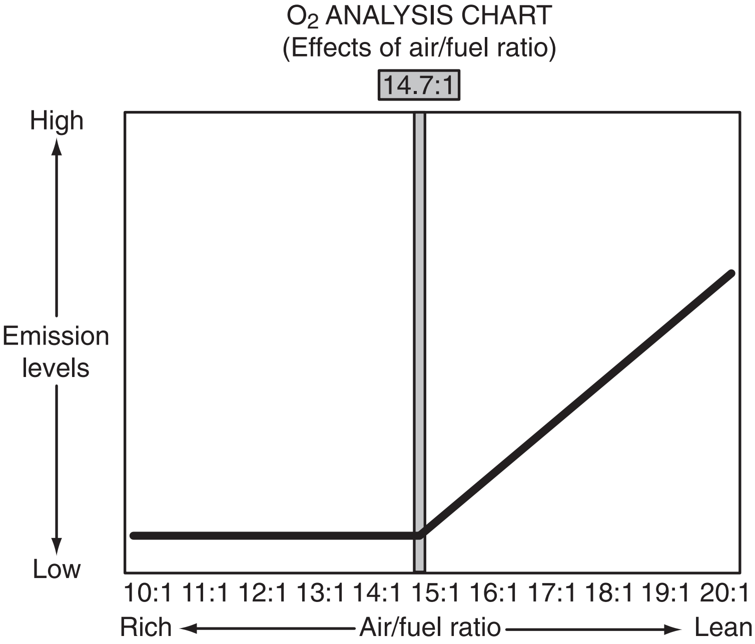


Figure 7–4 Effect of air/fuel ratio on oxygen.

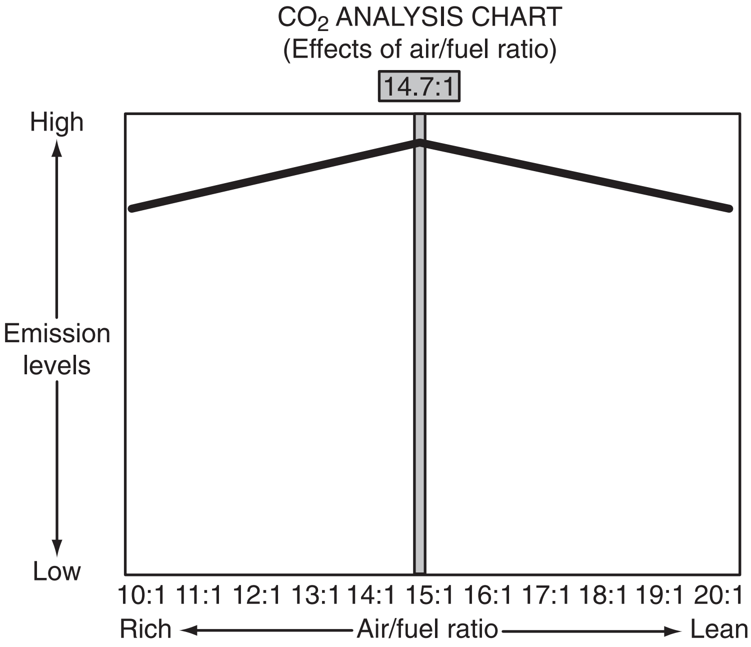


Figure 7–5 Effect of air/fuel ratio on carbon dioxide.

the exhaust system must be tight. Any extra air getting into the exhaust system falsely increases the O_2 levels and falsely minimizes the readings of all other gasses.

Effect of Air/Fuel Ratio on Carbon Dioxide. Carbon dioxide levels will be at their highest point when the engine is running at its greatest efficiency. Anything that reduces this level of efficiency also reduces the CO_2 levels. Mechanical or ignition misfire, misadjusted spark timing, and an improper air/fuel ratio all have the potential to reduce CO_2 levels. If the air/fuel ratio is either too lean or too rich, CO_2 is reduced (Figure 7–5). CO_2 will be at its highest level at the stoichiometric air/fuel ratio.

Effect of Air/Fuel Ratio on Oxides of Nitrogen. Levels of oxides of nitrogen are elevated dramatically when both sufficient temperature and pressure exist within the cylinder to achieve temperatures of about 2500°F or more. (An increase in cylinder pressure also elevates cylinder temperature.) Combustion in the cylinder reaches its peak temperature slightly to the rich side of stoichiometric, at around 14:1 (Figure 7–6). In terms of temperature alone, it is at this point that the potential for maximum NO_x production is reached. With a slightly rich mixture, however, most of the oxygen is consumed during the combustion process with little left to allow NO_x to form. As a result, in a properly running engine, this is not the point of maximum NO_x production; rather, actual NO_x production tends to increase as the air/fuel ratio moves leaner up to somewhere between 15:1 and 16:1 (just slightly to the lean side of stoichiometric). This is because the leaner air/fuel ratio provides more leftover oxygen for NO_x to form and the cylinder temperature is still high enough to allow for NO_x production.

Another reason that NO_x levels (as measured at the tailpipe) are seen to increase as the air/fuel ratio becomes leaner beyond 14.7:1 is that a lean air/fuel ratio does not support the operation of the NO_x reduction bed of the catalytic converter: the converter actually needs CO, formed only when the air/fuel mixture is rich, to help break up the

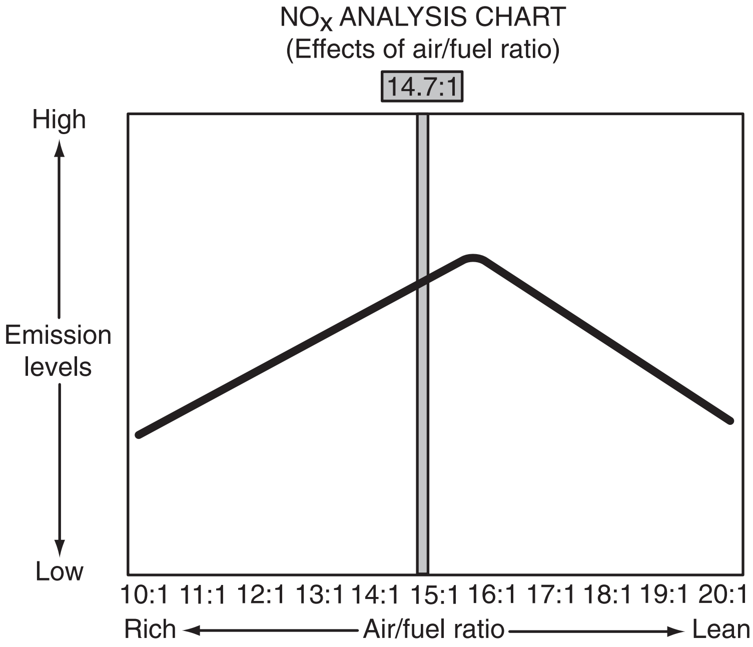


Figure 7–6 Effect of air/fuel ratio on oxides of nitrogen.

NO_x molecules. As a result, with the NO_x reduction catalytic converter working properly, NO_x levels after the converter will increase as the air/fuel ratio becomes leaner up to the point at which the NO_x production within the engine subsides.

Spark knock and ping can cause NO_x formation due to the resulting pressure increase. As a result, anything that tends to promote spark knock and ping can raise NO_x levels, including problems with turbocharger intercoolers, thermostatic air cleaners, and the like.

However, a few myths associated with NO_x production must be addressed:

- High engine temperature due to an overheated engine does not directly increase NO_x production. Even a coolant temperature of 300°F cannot directly push cylinder combustion temperature past 2500°F. (The only exception to this involves the extent to which an overheated engine might contribute to spark knock or ping.)
- Rich air/fuel mixtures do not cool the combustion but rather tend to burn a little hotter than a stoichiometric mixture, particularly if just slightly on the rich side of stoichiometric.
- While high engine loads tend to produce more pressure, resulting in higher cylinder temperatures, they do not actually result in higher levels of NO_x production in an engine that is controlling the air/fuel ratio properly. This is due to the fact that rich air/fuel ratios are required to achieve good engine performance under high load, and, as a result, not much oxygen remains after combustion has taken place. Without the oxygen, NO_x does not form. As a result, most NO_x production takes place in the light to medium load ranges when the air/fuel ratio is not as rich.

If an engine is running abnormally lean during a hard acceleration due to a restricted fuel filter, restricted fuel injectors, and the like, the potential exists for the engine to produce high levels of NO_x. This is because higher cylinder temperature is present due to the high load that the engine is under during hard acceleration, and with an abnormally lean condition plenty of oxygen is available as the combustion temperature peaks out. This combination allows for the formation of excessive NO_x within the combustion chamber.

GAS ANALYZERS

Concentration Sampling

The concentration sampling gas analysis machine is the analyzer found in most automotive shops today. Its design may be a big box type (Figure 7–7), or it may be portable (Figure 7–8). A probe, which is simply inserted into the exhaust pipe, allows the analyzer to sample a small percentage of the total exhaust gas volume when the engine is running. Each of the gasses is measured as a percentage, or concentration, of the total sample; thus the term **concentration sampling.**

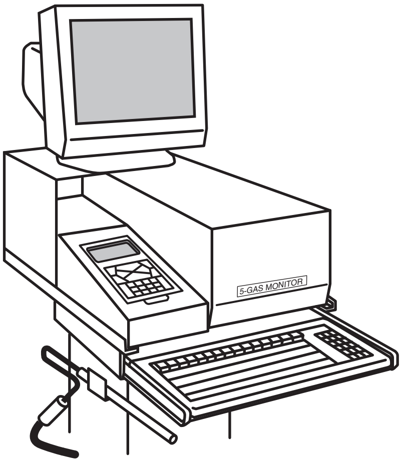


Figure 7–7 Five-gas emissions analyzer. (Courtesy of OTC Division, SPX Corporation.)

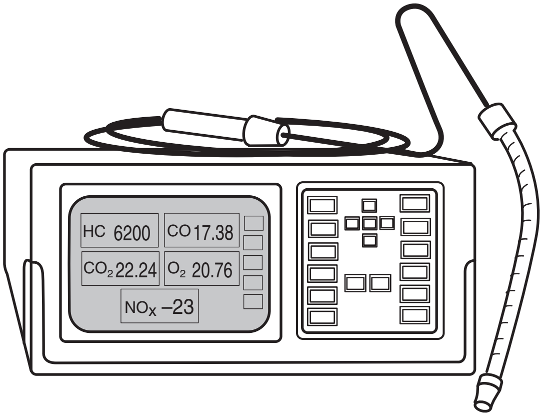


Figure 7–8 A portable exhaust gas analyzer.

All the measured gasses are measured either as a percentage (parts per hundred) or as parts per million (PPM), with PPM simply being a smaller-scale measurement. Because concentration sampling is the method used in most shops, as atechnician you must have a thorough understanding of the levels to expect of each of the gasses from a well-tuned running engine. Keep in mind that these figures are guidelines only and the results will vary with the year and model of each vehicle. Also, many states issue emission test cut-points for the various years and classifications of vehicles. Such cut-points do not reflect the ideal emission levels for these gasses but reflect only the point at which the particular state has chosen to fail the vehicle during an emission test. However, these cut-points can give you some indication of what emission levels to expect if you remember that these cut-points are usually quite generous.

This type of emissions testing is usually done in the shop with the vehicle at idle or at 2500 RPM, but it does not require the vehicle to be under any operating load. Therefore, this type of test is also referred to as a *no-load emission test.* If you have access to either a dynamometer or a portable gas analyzer that can monitor emission levels while the vehicle is being driven on public roads, you will be able to monitor emissions with the engine under load, which increases the ability of the analyzer to identify problem areas. In most shops, however, the test is still done without the vehicle being under any engine load. Some portable gas analyzers are available that have the ability to record and graph the emission readings while the vehicle is being driven.

WARNING: Looking away from the road to monitor a portable gas analyzer while driving is extremely dangerous. You should have another technician drive the vehicle for you, allowing you to concentrate on the gas analyzer readings.

Maximum CO Level. A concentration analyzer measures carbon monoxide levels in percent. CO levels should stay below 2.5 percent to 3 percent if the vehicle does not have a catalytic converter or if the converter is not up to operating temperature. With a converter that is up to operating temperature, CO levels should stay below 0.5 percent, preferably near 0 percent.

Maximum HC Level. A concentration analyzer measures hydrocarbon levels in PPM. HC levels should stay below 300 to 400 PPM if the vehicle does not have a catalytic converter or if the converter is not up to operating temperature. With a converter that is up to operating temperature, HC levels should stay below 100 PPM, preferably near 0 PPM.

Maximum O_2 Level. A concentration analyzer measures oxygen levels in percent. O_2 levels should absolutely stay below 2 percent to 3 percent. With good closed loop control, the O_2 level should be below 0.5 percent. O_2 levels above this level indicate that the air/fuel ratio is too lean, possibly approaching the area of a lean misfire. Any extra air entering the exhaust system artificially increases O_2 levels and artificially minimizes the levels of all other gasses. Remember to disable any secondary air injection system by pinching off the air hoses and to check the exhaust system for leaks.

Minimum CO_2 Level. A concentration analyzer measures carbon dioxide levels in percent. CO_2 levels will generally be above 12 percent to 13 percent. CO_2 may reach as high as 15.5 percent. Because engine design parameters (such as valve timing and lift) affect CO_2 levels, it is not possible to set a hard specification for CO_2. Therefore, if the CO_2 is reading close to 15.5 percent, the engine is likely performing well. If the CO_2 is reading at 11 percent or less, the engine likely has performance problems that must be diagnosed. If the CO_2 is between 12 percent and 14 percent, it could mean that the engine is performing well, but it could also mean that there are performance problems with the engine. For example, an engine that emits 15.5 percent CO_2 when running at its peak efficiency might only emit 13 percent CO_2 when a problem is present. Therefore, the technician must evaluate all of the other gasses when making a determination.

Measuring NO_x Levels. A concentration analyzer measures NO_x levels in PPM. Having the ability to measure NO_x is not critical unless you are in an area where vehicles are tested and failed for NO_x; otherwise, the ability to measure NO_x levels is not as important to your diagnosis as the ability to measure the other gasses. NO_x is best measured when the vehicle is under normal load because an engine that is not under load may not produce the NO_x levels that would be recorded during an emission test that loaded the vehicle. A dynamometer may be used if you have access to one. Otherwise, drive the vehicle on a road test while recording the results on a portable five-gas analyzer. Make sure your drive cycle is repeatable. Although your concentration-type analyzer shows NO_x in PPM, you can compare the readings obtained following your repairs to your initial readings to see if you made an improvement.

When diagnosing a vehicle that has failed for high NO_x, think in terms of high combustion chamber temperatures. Many engines use EGR and/or variable valve timing to recycle exhaust gasses as a method of helping to control these temperatures. Thus, these systems should also be checked. In addition, the engine should be checked for running lean on acceleration due to a restricted fuel filter or restricted fuel injectors. Also, if a failure for high CO is being diagnosed and NO_x is also quite high (whether it fails or not), keep in mind that as the CO problem is corrected and the air/fuel ratio is leaned out toward stoichiometric, additional air will be made available for NO_x formation. If cylinder temperatures are already high, NO_x levels may be increased even as the CO problem is corrected.

No-Load Emission Test. Some states use a concentration method of exhaust sampling to sample emissions under no load at idle, then at 2500 RPM, and then again at idle. This type of test may be referred to as a *no-load test* or an *idle test.* The measured emissions at 2500 RPM may or may not be used as a pass/fail standard. This type of testing is used most often with older vehicles, but may be used with newer vehicles in less densely populated areas.

Acceleration Simulation Mode Test. Several states have adopted an emissions program referred to as an *acceleration simulation mode* (ASM) test. The ASM test uses a concentration method of exhaust sampling combined with the use of a dynamometer to test CO, HC, and NO_x levels under vehicle load. The ASM test is divided into two parts. During the ASM 5015 part of the test, the vehicle is driven on a dynamometer at 15 mph. During the ASM 2525 part of the test, the vehicle is driven on a dynamometer at 25 mph. Both ASM tests require that the vehicle must pass concentration-type emissions standards for at least 10 seconds of a 90-second test, beginning no sooner than 25 seconds into the test. The results of either the idle test or the ASM test are measured in percent and parts per million.

Constant Volume Sampling

Several states have now adopted an emissions-testing program that imitates some characteristics of the federal test procedure (FTP) used to certify new vehicles before they are made legal for sale in the United States. This test, called an *inspection/maintenance test* (I/M test), places the vehicle under realistic load on a dynamometer designed to imitate the vehicle's curb weight, wind resistance, and other rolling resistance. If the vehicle is run for 240 seconds on the dynamometer during the test, the test is referred to as an *IM240 test* (Figure 7–9). An IM240 emission test uses a process called **constant volume sampling (CVS),** which requires that all of the exhaust be captured and measured along with enough ambient air to create a known volume of gasses. Then the density of this known volume is calculated. Finally, the concentration (percentage) of each gas is calculated to figure how many grams of each gas are being expelled from the exhaust system. The analytical computer is also able to use the dynamometer to determine the distance the vehicle has traveled at any instant in time or over a longer time period. Ultimately, each gas is calculated in **grams per mile (GPM).**

Constant volume sampling generally tests for four gasses: the three primary toxic gasses (CO, HC, and NO_x) and one nontoxic gas (CO_2). The primary advantage of this type of test is that it tests the vehicle under realistic load conditions. Sometimes the engine computer's strategies are different when the engine is not under load than when the vehicle is driven down the road. Or a secondary spark plug wire that is developing poor insulation

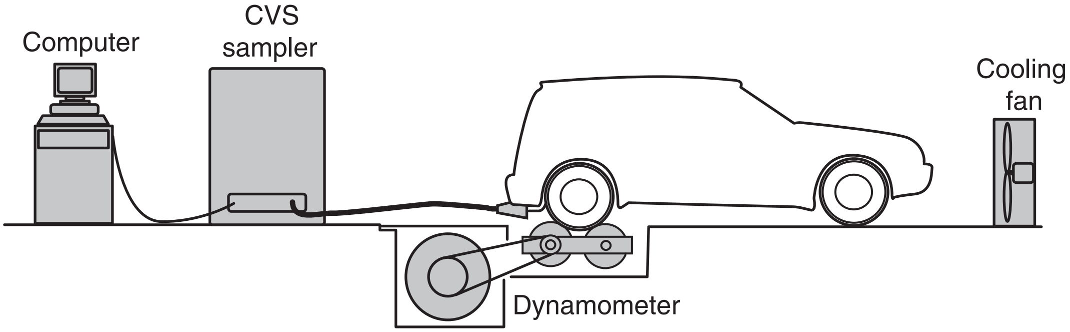


Figure 7–9 Components of a typical IM240 test station.

may only arc to the engine block when under realistic load because of the increased cylinder pressures when under load. This same problem may not show up at all during a no-load emission test due to the fact that the spark plug gap may continue to be the path of least resistance when cylinder pressures are low. Ultimately, the best method to test how many emission gasses exit the tailpipe when the vehicle is traveling on the road is to test the vehicle under the same conditions.

You should also be aware that most CVS analytical equipment used with IM240 testing uses a process called "flame ionization" to evaluate HC emissions. Unlike the infrared benches used in concentration sampling analyzers, these units are sensitive to hydrocarbons from antifreeze and brake fluid. Because of the manner in which these analyzers draw in additional make-up air near the rear of the vehicle, they also may pick up gasoline hydrocarbons from fuel line leaks near the front of the vehicle or from evaporative system vapor leaks, since all of this is blown toward the rear of the vehicle during the IM240 dynamometer test. Therefore, when diagnosing hydrocarbon failures resulting from an IM240 test, in addition to measuring the hydrocarbon emissions exiting the tailpipe, be sure to perform visual checks for gasoline, brake fluid, and antifreeze leaks, and to conduct a visual inspection of the hoses associated with the evaporative/canister purge system.

DIAGNOSING WITH THE GASSES

Concentration Sampling

Because most automotive shops have the ability to perform concentration sampling of exhaust gasses either with a big box-type scope or with a portable gas analyzer, the emphasis of this book is on this type of testing.

When using gas analysis to aid in diagnosing engine performance problems, fuel economy problems, or emission test failures, the technician should record the readings of all gasses at both idle and 2500 RPM. It is critical to test CO, HC, O_2, and CO_2 levels for best engine performance evaluation. If you are working in an emission program area that tests for NO_x, you should have a gas analyzer that also tests for NO_x.

If the reason that you are testing for emission levels is that the vehicle failed an emission test, you should record both before and after repair readings. Although this is always a good idea, it is especially important if the emission test performed on the vehicle produced exhaust gas readings in GPM, as there is no way to reliably convert GPM into percent or PPM. Taking exhaust gas readings before you make any repairs (even before you perform a visual inspection or wiggle any electrical connectors) is known as *baselining.* Baselining the vehicle before you make any repairs allows you to take exhaust gas readings after the repairs have been made and compare them to the baseline readings to determine whether your repairs have been effective.

Preparing the Gas Analyzer

Before the vehicle is tested, the gas analyzer should be properly warmed up. The analyzer should also be calibrated weekly using a calibration gas and following the manufacturer's specified procedures for the particular analyzer. This test usually includes a leak test of the probe and sample hose.

Before each test, the probe should be left open to sample ambient air while the readings are evaluated. HC, CO, and CO_2 should read very close to zero. O_2 levels should read between 20 percent and 21 percent. If they do not, the O_2 sensor in the analyzer should be replaced. (It is also a good idea to watch the O_2 reading when the gas calibration is performed. It should show very close to zero during the calibration.)

Evaluating the Gasses

This author recommends that the technician first evaluate CO_2 levels, both at idle and 2500 RPM, to make a quick determination concerning the efficiency of the engine at both engine speeds. If the CO_2 is low at either measurement, you know a problem exists at that engine speed. However, even if the CO_2 is high, evaluate the other gasses as well. Do the other gasses also support the high level of CO_2 or should the CO_2 be even higher still?

Once the CO_2 has been evaluated, look at leftover O_2 to check for a lean engine operating condition with either test. (The air injection system must be disabled.) If the engine is running lean at idle but is performing well at 2500 RPM, check for vacuum leaks. Conversely, if the engine is running lean at 2500 RPM but is performing well at idle, check for a partially plugged fuel filter.

Look at CO levels to check for a rich engine operating condition at either RPM, while keeping in mind that if the catalytic converter is hot, this value may be falsely minimized. (If you are evaluating emission levels to perform an emission test, you want the converter to be up to full operating temperature. But if you are evaluating emission levels for diagnostic purposes, it is best if you avoid getting the converter up to full operating temperature if possible.) If the engine is running rich at idle but is performing well at 2500 RPM, check for misadjusted idle mixture screws (carbureted engines) or a small diaphragm tear in the fuel pressure regulator (fuel-injected engines). Of course, larger tears in the regulator's diaphragm will cause overly rich conditions at both engine speeds. Conversely, if the engine is running rich at 2500 RPM but is performing well at idle, check for a partially plugged air filter.

Look at HC levels to check for indications of a misfire condition at either RPM, while keeping in mind that if the catalytic converter is hot, this value may be falsely minimized.

If HC levels are *moderately* high and CO levels are also high, the HC levels are high because the air/fuel ratio is rich. For example, 6.50 percent CO can also be responsible for an HC reading of around 650 PPM. When you correct the overly rich condition to decrease CO levels, HC levels also decrease.

If HC levels are *dramatically* high, a total misfire is present (although it may be intermittent), either due to an ignition misfire, a lean misfire, or mechanical problems. For example, with a CO reading of 6.50 percent and an HC reading of 1700 PPM, we would know that the engine is experiencing at least two problems. While a CO reading of 6.50 percent indicates a rich air/fuel ratio, 6.50 percent CO cannot be the only cause of an HC reading of 1700 PPM. In this instance, the engine has a total misfire, either mechanical or ignition-related, in addition to the rich air/fuel ratio that is causing the high CO reading. (You can rule out a lean misfire due to the high CO reading.)

If HC levels are high at 2500 RPM only or are high at both engine speeds, you must scope the secondary ignition system. Ignition misfire problems do not decrease with increased RPM. That is, if HC levels are high at idle but are normal at 2500 RPM, the problem is not ignition-related but is due to either a lean misfire or mechanical problems. At this point you may add propane (using a propane enrichment tool) to artificially enrich the air/fuel ratio. If the HC levels now decrease, the problem is air/fuel ratio related. If the HC levels stay high, you should run engine compression tests.

Treat an exhaust gas analyzer as a "narrow down the problem area" type of tool. It is not a pinpoint test tool. For example, if a high CO reading is obtained, you know that the engine is running rich, due to either too little air or too much fuel being delivered. But the high CO reading does not immediately define for you the exact cause of the problem—it only narrows down the possible areas that you need to pinpoint test.

CAUTION: Never spray carburetor cleaner into the throttle body on a running engine as a method of artificial enrichment while a gas analyzer's probe is in the tailpipe. You may damage internal components of the gas analyzer.

Other Tests

A gas analyzer may also be used to perform certain other tests. For example, if you remove the radiator cap from the radiator while the engine is cold and then start the engine, you can use the analyzer probe to check for hydrocarbons (or even

CO or CO_2) escaping from the radiator. Most gas analyzers that use concentration sampling use infrared analytical equipment to test for CO, CO_2, and HC emissions and are therefore not sensitive to antifreeze hydrocarbons. Therefore, if any of these emissions are present at the radiator, a head gasket leak (or cracked head) is indicated.

CAUTION: Never allow the analyzer probe to suck in liquid coolant because it will damage the gas analyzer.

An additional test that may be performed with a gas analyzer is a test for the ability of the ignition and fuel management systems to deliver spark and fuel to each of the cylinders. For example, if a cylinder power balance test shows that one of the cylinders is performing poorly but emission levels seem to be normal, use the scope to perform the cylinder power balance test again while watching the emissions gas levels. When the scope disables the spark for each cylinder, if fuel is being delivered the HC levels should increase dramatically. When the spark is re-enabled, the HC levels should decrease again. This test may also be run manually by placing a small wire under the plug wire boot (at either end of the plug wire), then using a grounded test light to short the spark to ground. If the HC levels remain very low when the spark is shorted to ground through the test light, fuel is not being delivered to that cylinder. Conversely, if HC levels are always high and shorting the spark to ground makes little difference, spark is likely not being delivered to that cylinder.

Keep in mind that the ability to use a gas analyzer to evaluate HC levels can allow you to diagnose other sources of unburned fuel, such as leaking mechanical fuel pumps or leaking fuel injectors. To evaluate leaking fuel injectors associated with a loss of residual fuel pressure with a PFI system, start the engine and let it idle several minutes. Then shut it off for 5 minutes, during which time you should electrically disable the fuel injectors and ignition system. Also, remove all of the spark plugs. After the 5 minutes are up, crank the engine for about 15 seconds. Then use a gas analyzer to “sniff” each spark plug hole. Normal cylinders will register hydrocarbon levels of approximately 125 to 150 PPM. Cylinders with leaking fuel injectors will show dramatically higher hydrocarbon levels, usually around 5000 to 10,000 PPM. If leaking injectors are identified, cleaning them will sometimes correct the problem.

CO_2 Update

Because CO_2 is a by-product of an internal combustion engine and because it is believed that excessive CO_2 production may have some effect on global warming, regulations are being considered to control CO_2 emissions. In fact, the California Air Resources Board has already adopted such regulations. As a technician, you should know that this does not change the way that you use CO_2 as an analytical tool. CO_2 is still considered nontoxic, and it is still desirable to use it as an indicator of engine efficiency. In fact, the only way to reduce CO_2 emissions is to burn less fuel—that is, to increase a vehicle’s fuel economy. The technologies that are being used to reduce CO_2 emissions include variable valve timing, turbocharging/supercharging, cylinder deactivation during cruise, six-speed automatic transmissions, integrated starter/generators, camless valve actuation, braking regeneration, and hybrid vehicles (see Chapter 18). Ultimately, CO_2 reduction can only occur as we develop technologies that increase a vehicle’s fuel economy.

SUMMARY

This chapter described how each of the exhaust gasses is produced and what emission levels mean in terms of diagnostic purposes. We reviewed some basic informations on the types of analyzers, what they mean to the technician, and the importance of baselining a vehicle before making any repairs. We also discussed how gas analysis can be used to quickly isolate the general problem area to reduce the amount of pinpoint testing that must be done during diagnosis.

▲ DIAGNOSTIC EXERCISE

A fuel-injected vehicle is pulled into the shop with a complaint of poor gas mileage and poor performance. The engine is properly warmed up and in closed loop for all of the following tests. A scan tool shows that the oxygen sensor is stuck lean and the PCM is commanding a wide pulse width to the fuel injectors. Further testing proves that the oxygen sensor is okay. A gas analyzer probe is inserted in the tailpipe. To accurately measure the emission gasses, the technician disables the air injection system. All emission gasses are normal at both idle and 2500 RPM. Additionally, the technician notices that the scan tool is now showing that the O_2 sensor is cross-counting and the injector pulse width is normal. At this point the technician re-enables the air injection system. The scan tool again shows that the O_2 sensor is stuck lean and the PCM is commanding a wide pulse width to the injectors, but the gas analyzer is showing a high level of CO at both idle and 2500 RPM. What appears to be wrong?

Review Questions

1. Which of the following best describes the primary make-up of atmospheric air?
   A. 21 percent CO and 78 percent O_2
   B. 21 percent O_2 and 78 percent N_2
   C. 21 percent N_2 and 78 percent O_2
   D. 21 percent O_2 and 78 percent H_2O
2. Which of the following emissions of a gasoline engine does a five-gas analyzer not measure?
   A. H_2O
   B. CO
   C. CO_2
   D. O_2
3. Which of the following emission gasses should be as high as possible and is an efficiency indicator?
   A. O_2
   B. HC
   C. CO
   D. CO_2
4. Higher-than-normal HC emission levels may be the result of which of the following?
   A. An ignition misfire, a lean misfire, or a mechanical misfire
   B. An overly rich air/fuel ratio
   C. High combustion chamber temperatures
   D. Both A and B
5. Higher-than-normal CO emission levels may be the result of which of the following?
   A. An ignition misfire, a lean misfire, or a mechanical misfire
   B. An overly rich air/fuel ratio
   C. High combustion chamber temperatures
   D. Both A and B
6. Higher-than-normal NO_x emission levels may be the result of which of the following?
   A. An ignition misfire, a lean misfire, or a mechanical misfire
   B. An engine that is slightly overheated
   C. High combustion chamber temperatures
   D. Both B and C
7. Technician A says that, on an engine that is running properly, most NO_x production occurs during periods of high engine load. Technician B says that if the air/fuel mixture is slightly richer than stoichiometric, NO_x will not form due to the cooling effect of the fuel. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
8. Which of the following describes concentration sampling?
   A. Uses a dynamometer to load the engine to realistic loads
   B. Captures all of the exhaust and displays each gas as GPM
   C. Samples only a small portion of the total exhaust sample, then displays each gas as either percent or PPM
   D. Both A and B
9. Which of the following describes constant volume sampling?
   A. Uses a dynamometer to load the engine to realistic loads
   B. Captures all of the exhaust and displays each gas as GPM

C. Samples only a small portion of the total exhaust sample, then displays each gas as either percent or PPM
D. Both A and B

10. When diagnosing engine performance problems, it is important to disable the air injection system and to be sure that the exhaust system does not leak when using a gas analyzer that uses concentration sampling. This is because any extra air getting into the exhaust system will do which of the following?
    A. Falsely decrease O_2 readings
    B. Falsely increase O_2 readings
    C. Falsely decrease the readings of all of the other measured gasses (except O_2)
    D. Both B and C
11. If a gas analyzer's probe is placed near a fuel line leak, the analyzer readings will show an increase in which of the following?
    A. H_2O levels
    B. CO levels
    C. HC levels
    D. Both B and C
12. When a gas analyzer is properly warmed up and the probe is sampling ambient air, what should the O_2 level read?
    A. 0 percent
    B. Between 1 percent and 5 percent
    C. Between 20 percent and 21 percent
    D. About 78 percent
13. How would an ignition misfire affect the following gasses?
    A. O_2 levels would be lower; CO and CO_2 levels would be higher.
    B. CO_2 levels would be lower; O_2 and CO levels would be higher.
    C. CO_2 and CO levels would be lower; O_2 levels would be higher.
    D. CO_2 and O_2 levels would be lower; CO levels would be higher.
14. Technician A says that you should take exhaust gas readings before performing any repair work on a vehicle so that when the repair work is complete you have some initial gas readings with which to compare your final gas readings. Technician B says that to convert GPM emissions values into percentages (or concentrations), you must multiply the GPM by the atmospheric air pressure and then divide by 78 percent. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
15. The following readings are obtained on a gas analyzer:

	Idle	2500 RPM
HC	1335 PPM	112 PPM
CO	0.00 percent	0.48 percent
CO_2	8.90 percent	14.80 percent
O_2	6.80 percent	0.73 percent

    What type of problem is most likely indicated?

    A. Insulation breakdown on a secondary ignition wire
    B. A vacuum leak resulting in a lean condition at idle
    C. A plugged fuel filter resulting in a lean condition at 2500 RPM
    D. A plugged air filter resulting in a rich condition at 2500 RPM
16. The following readings are obtained on a gas analyzer:

	Idle	2500 RPM
HC	1585 PPM	1980 PPM
CO	0.00 percent	0.00 percent
CO_2	9.12 percent	7.98 percent
O_2	0.80 percent	0.96 percent

    What type of problem is most likely indicated?

    A. Insulation breakdown on a secondary ignition wire
    B. A vacuum leak resulting in a lean condition at idle
    C. A plugged fuel filter resulting in a lean condition at 2500 RPM
    D. A plugged air filter resulting in a rich condition at 2500 RPM

17. The following readings are obtained on a gas analyzer:

	Idle	2500 RPM
HC	10 PPM	560 PPM
CO	0.02 percent	6.70 percent
CO_2	15.12 percent	10.79 percent
O_2	0.70 percent	0.00 percent

What type of problem is most likely indicated?

A. Insulation breakdown on a secondary ignition wire
B. A vacuum leak resulting in a lean condition at idle
C. A plugged fuel filter resulting in a lean condition at 2500 RPM
D. A plugged air filter resulting in a rich condition at 2500 RPM

18. A vehicle that has failed an emission test for high CO comes into the shop. Technician A says that the spark plugs and spark plug wires may be at fault and should be replaced to correct this problem. Technician B says that the first thing that should be done is to test the vehicle on the shop's gas analyzer to verify the readings before any repairs are made. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

19. Which of the following could cause an IM240 test to fail a vehicle for high HC while a shop's concentration sampling gas analyzer might not be able to identify the source of the hydrocarbons with the probe placed in the tailpipe?

A. Fuel line leak near the front of the vehicle
B. Antifreeze leak near the front of the vehicle
C. Evaporative/canister purge system hoses disconnected
D. All of the above

20. A cylinder power balance test is being run on a vehicle with a V6 engine with port fuel injection while a gas analyzer is sampling the emission gasses. With all cylinders enabled, HC levels are low. When the spark for cylinders 1, 2, 4, and 6 is turned off individually, HC levels increase dramatically. When the spark for cylinders 3 and 5 is turned off individually, HC levels stay low. Technician A says that this is evidence that cylinders 1, 2, 4, and 6 are getting too much fuel. Technician B says that the fuel injectors at cylinders 3 and 5 may be plugged. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

Chapter 8

OBD II Self-Diagnostics

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

❑ Define the reasons for the OBD II program.
❑ Explain the major aspects of the OBD II program.
❑ Describe the features standardized for all manufacturers within the OBD II program.
❑ Understand the monitoring conditions that the OBD II PCM requires.
❑ Describe the conditions that will cause an OBD II PCM to set a diagnostic trouble code and turn on the malfunction indicator light.
❑ Explain the strategies of the diagnostic management software and the monitoring sequences required on all vehicles, both domestic and imported, by the OBD II program.
❑ Know how to approach an OBD II-equipped vehicle in terms of diagnostics.

KEY TERMS

Component ID (CID)
Continuous Monitor
Data Link Connector (DLC)
Drive Cycle
Efficiency Monitoring
Enable Criteria
Freeze Frame Data
Generic OBD II Mode
Global OBD II Mode
Hexadecimal
Intrusive Test
Malfunction Indicator Light (MIL)
Misfire Detection
Monitor
Non-Continuous Monitor
OBD II
Protocol
Rationality Testing
Snapshot
Test ID (TID)
Trip
VIN Entry Mode

Through the years, the federal government has been a driving force for change in the automotive industry. Federal regulations have changed not only for the domestic product but also for all vehicles marketed in the United States. The **second update of on-board diagnostic (OBD II)** standards has made both foreign and domestic vehicles more similar than dissimilar. This chapter demonstrates those similarities in a broad overview of new vehicles.

CARB/EPA/SAE/OBD BACKGROUND

In the 1970s, Congress recognized that the State of California had a more serious air quality problem than the rest of the United States and, therefore, granted California permission as a state to adopt its own regulations. The California Air Resources Board (CARB) is California's state agency charged with adopting regulations to achieve a healthy air quality for people living in that state. However, to avoid having 50 such independent sets of state regulations, the Environmental Protection Agency (EPA), as a branch of the federal government, was charged with achieving a healthy air quality for all people living in the United States.

Another group, the Society of Automotive Engineers (SAE), is a nonprofit organization that consists of more than 90,000 members (engineers, scientists, educators, and students from more than 97 countries) who are dedicated to sharing information and exchanging ideas for advancing the engineering of mobility systems, including designing, building, maintaining, and operating self-propelled vehicles. The EPA and CARB have worked together with SAE to set into place a number of regulations in recent years.

CARB adopted the original on-board diagnostic program (originally OBD, now known as OBD I) in 1985 for 1988 model-year vehicles. The OBD I regulation was less than one page in length and required several simple guidelines to be met, many of which were already being met by domestic manufacturers. In fact, General Motors provided some of the ideas that were used to develop OBD I regulations. These regulations only required that the PCM have the ability to recognize a component's total failure and alert the driver through a **malfunction indicator light (MIL).** There was no standardization associated with OBD I. As a result, the diagnostic connectors and diagnostic procedures varied greatly among manufacturers, making system diagnostics quite difficult for an aftermarket technician.

CARB, having realized how ineffective OBD I was, adopted OBD II regulations in 1989 for 1996 model-year vehicles. Simultaneously, the EPA decided to adopt the regulations on a national basis. (Though they were initially slated for the 1994 model year, it was decided to delay compliance requirements until the 1996 model year.) With the 1996 models, many car manufacturers built their first OBD II–compliant vehicles. The OBD II program is intended to standardize the diagnosis of emissions and driveability-related problems on all new cars sold in the United States. The new standardized self-diagnostic systems were installed on most cars for the 1996 model year. (Temporary waivers were allowed initially for some manufacturers with unique technical difficulties, but by the 1998 model year all manufacturers were required to be in compliance.)

CARB, the EPA, and SAE work together to continue to update and enhance these regulations on a regular basis, about every two years, to keep pace with new emissions controls and technology.

WHY OBD II?

The OBD II system (and its predictable successors) should be the basis for driveability and emissions diagnosis for many years to come. It makes diagnostic tools, codes, and procedures similar, regardless of manufacturer or country of origin. The system was originally crafted to allow plenty of room for growth and the incorporation of additional subsystems. While there are some differences among carmakers and among models (because of different system control components), the purpose of the program is to make the diagnosis of emissions and driveability problems simple and uniform; it will no longer be necessary to learn entirely new systems for each manufacturer.

The chemistry of gasoline combustion, the mechanics of a four-cycle engine, and the emissions control strategies that have proven to be successful are the same for all carmakers. These facts, plus federal law, should make emissions and driveability diagnosis both more successful and easier to learn in the future.

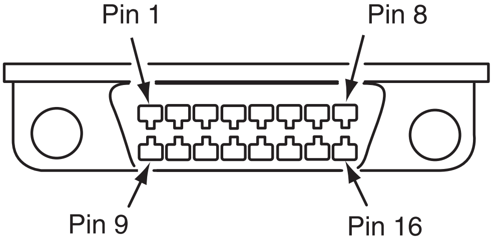
Much of this information involves technical changes introduced gradually, since emissions concerns first began to shape combustion control measures and since, in any given year, most carmakers' changes are largely enhancements or refocusing of systems introduced previously. Some subsystems described here, such as the PCV system, appeared on the automobile as early as 1961 (California models) and 1963 (Federal models); others appeared on only a few early OBD II models, and some will remain unique to specific vehicles. The OBD II system affords the options to accommodate all of this.

WHAT DOES OBD II DO?

The idea behind OBD II is that any properly trained automotive service technician can effectively diagnose any engine performance, fuel economy, or emissions concern on any vehicle built according to the OBD II standard, using the same diagnostic tools, regardless of vehicle make. As a result, vehicles will be better maintained by the repair industry, thus improving the overall air quality. OBD II standards have since been enhanced to provide additional manufacturer service information to the repair industry to help aftermarket technicians achieve more effective repairs. Meanwhile, carmakers can introduce special diagnostic tools or capacities for their own systems, as long as standard scan tools, along with digital volt-ohmmeters and oscilloscopes, can analyze the systems. These tools can, of course, have additional capacities beyond the designated OBD II–required functions. One of the mandated capacities of OBD II systems, for example, is **freeze frame data,** the ability of a system to record data from its sensors and actuators at the time when the system turns on the MIL. General Motors expands this capacity to include “failure records,” which does the same thing as freeze frame but includes any fault stored in the computer’s memory, not just those related to emissions component circuit failures. Another mandated capacity is the ability of the PCM to run specific tests from time to time, known as a monitoring sequence or **monitor.** This allows the PCM to make required specific tests.

The goal of OBD II is to monitor the effectiveness of the major emissions controls and to turn on the MIL and store a DTC whenever system effectiveness deteriorates to the point where the emissions level reaches 1.5 times the allowable standard for a particular grade of gas and vehicle, based on the federal test procedure (FTP).

Besides enhancements to the computer’s capacities, the program requires some additional sensor hardware to monitor emissions performance closely enough to fulfill the tighter constraints, beyond merely keeping track of component failures. In most cases this hardware consists of an additional heated oxygen sensor down the exhaust stream from the catalytic converter, upgrading specific connectors and components to last the mandated 100,000 miles or 10 years, in some cases a more precise crankshaft or camshaft position (CMP) sensor (to detect misfires more accurately), and the new standardized 16-pin **data link connector (DLC)** (Figure 8–1).



Pin 1: Manufacturer discretionary
Pin 2: J1850 bus positive
Pin 3: Manufacturer discretionary
Pin 4: Chassis ground
Pin 5: Signal ground
Pin 6: Manufacturer discretionary
Pin 7: ISO 1941-2 "K" line
Pin 8: Manufacturer discretionary

Pin 9: Manufacturer discretionary
Pin 10: J1850 bus negative
Pin 11: Manufacturer discretionary
Pin 12: Manufacturer discretionary
Pin 13: Manufacturer discretionary
Pin 14: Manufacturer discretionary
Pin 15: ISO 9141-2 "L" line
Pin 16: Battery power

Figure 8–1 Standardized OBD II diagnostic link connector (DLC).

STANDARDIZATION

Besides the closer monitoring of emissions performance, the other major change of OBD II is the standardization of diagnosis. While not all vehicles use identical systems, there is much overlap in the types of systems used (catalytic converters, oxygen sensor feedback), and the OBD II program is designed to reduce the confusion among systems by mandating not only the standard diagnostic link but also the specific codes and descriptions of components in manufacturers' literature. These standards and standard descriptions and trouble codes were all prepared by the SAE to achieve the following:

- common protocol standards (SAE standard J1850)
- common terms and acronyms (SAE standard J1930)
- common DLC (SAE standard J1962)
- common DLC location (SAE standard J1962)
- common diagnostic trouble codes (SAE standard J2012)
- common OBD II scan tools (SAE standard J1979)
- common generic (global) diagnostic test modes (SAE standard J2190)

Common Protocol Standards (SAE Standard J1850)

A **protocol** in computer language is merely an agreed-upon digital binary code (or language) a computer uses to communicate with a scan tool. Compliance with OBD II standards means each manufacturer must use a standardized multiplexing protocol between the PCM and the scan tool that is connected to the DLC for diagnostic purposes when diagnosis of any system that affects the vehicle's emissions is concerned. (For more information on this, see Chapter 9.)

Common Terms and Acronyms (SAE Standard J1930)

All vehicle manufacturers must employ common names and abbreviations, or acronyms, for components serving similar purposes (Figure 8–2). For example, the sensor reporting crankshaft position (CKP) and speed information to the computer will be called a CKP sensor by each manufacturer, and it will be abbreviated CKP. The computer that is in charge of controlling engine performance will be described as the powertrain control module (PCM). Previously, the PCM might have referred to as the electronic control module (ECM), electronic control assembly (ECA), or electronic control unit (ECU), depending upon the manufacturer. Most manufacturers began using the new terms for their 1993 model-year vehicles.

Common Data Link Connector (SAE Standard J1962)

All OBD II vehicles have a standardized DLC, also sometimes referred to as a *diagnostic link connector,* which has a standardized shape, size, and terminal pin-out (Figure 8–1), thereby allowing a scan tool with a standardized adaptor to be used on all OBD II vehicles, regardless of manufacturer. The DLC contains seven pins that have been standardized according to use. The other nine pins are discretionary and may be used by the manufacturer for any purpose. The DLC is designed for use with a scan tool only. No jumper connections should be made at the DLC as was sometimes done with pre–OBD II systems. Also, the DLC contains the scan tool power and ground circuits, so that a separate power circuit is no longer required, as it was for previous systems.

Common DLC Location (SAE Standard J1962)

The DLC also has a standardized location. Initially, the location was required to be in a position between the left side of the interior

Old Acronyms			New Technology, All Manufacturers	
Chrysler	**Ford**	**GM**	**Acronyms**	**Terms**
SMEC/SBEC	ECA	ECM	PCM	Powertrain control module
Diag. test connector	Self-test connector	ALDL	DLC	Data link connector
DIS	DIS/EDIS	DIS/IDI/C3I	EIS	Electronic ignition system
CTS	ECT	CTS	ECT	Engine coolant temperature sensor
EVAP	CANP	CANP	EEC	Evaporative emission control solenoid
—	SPOUT	EST	IC	Ignition control
—	Dis module	C3I module	ICM	Ignition control module
CTS	ACT	MAT	IAT	Intake air temperature sensor
KS	KS	DS	KS	Knock sensor
—	PSPS	PS switch	PSP	Power steering pressure switch
PLL/Check engine light	MIL	Check engine/ Service engine	MIL	Malfunction indicator lamp
TPS	TPS	TPS	TPS	Throttle position sensor
—	BP	BARO	BARO	Barometric pressure
Brake switch	BOO	Brake switch	BOO	Brake on/off switch
Sync	CID	Sync	CMP	Camshaft position sensor
REF pickup	CPS	REF	CKP	Crankshaft position sensor
—	PFE		DPFE	Differential pres. feedback EGR
—	TFI-IV	HEI	DI	Distributor ignition
HO$_2$	HEGO	HO$_2$	H$_2$OS	Heated oxygen sensor

Figure 8–2 A partial list of J1930-standardized terminology and acronyms.

compartment and a position 300 mm (approximately 1 foot) to the right of the vehicle centerline (Figure 8–3). Unfortunately, this left the manufacturers a lot of latitude in locating the DLC. Some manufacturers even placed the DLC inside of, or to the rear of, the center console or even behind or underneath an ashtray. The EPA has since updated this, now requiring the DLC to be located to the left of the vehicle centerline and from a position below the instrument panel to about halfway up the instrument panel (Figure 8–4). As of the 2003 model year, CARB regulations further restricted this placement, requiring that the DLC be located to the left of the vehicle centerline and underneath the instrument panel, in a position below the lower edge of the steering wheel when adjusted to its lowest position (Figure 8–5). If the vehicle is equipped with a center console, the DLC must be placed to the left of it. If the manufacturer chooses to place a dustcover over the DLC, the cover must be labeled and the technician must be able to remove it without tools. Furthermore, CARB requires that the DLC must be in a position accessible to a technician entering the vehicle in a crouched position.

Common Diagnostic Trouble Codes (SAE Standard J2012)

SAE J2012 determines a five-character alphanumeric code in which each character has

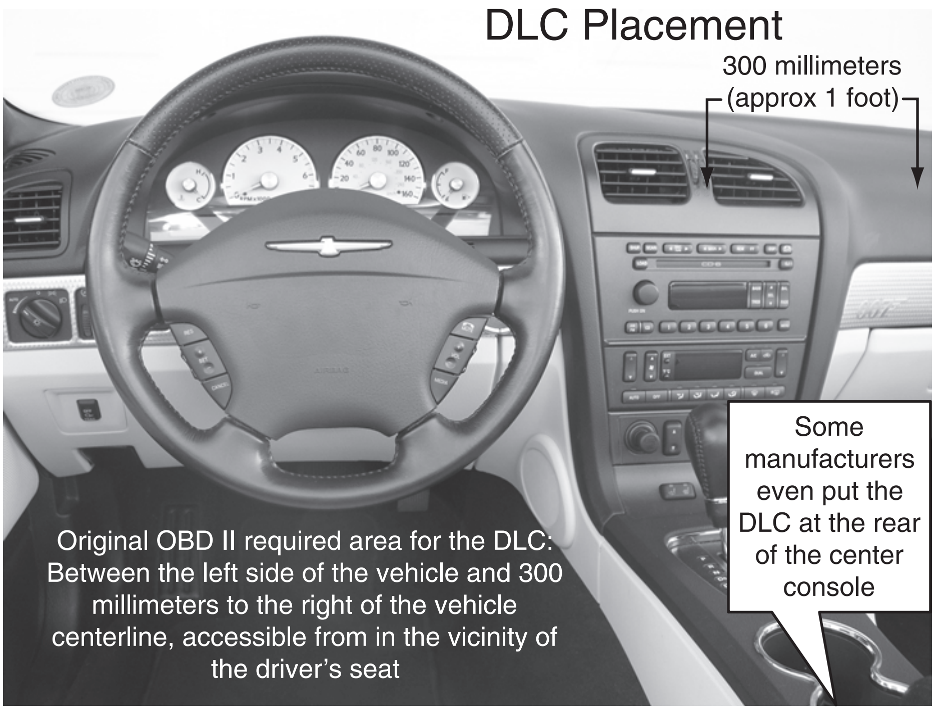

DLC Placement
300 millimeters
(approx 1 foot)
Original OBD II required area for the DLC: Between the left side of the vehicle and 300 millimeters to the right of the vehicle centerline, accessible from in the vicinity of the driver's seat
Some manufacturers even put the DLC at the rear of the center console

Figure 8–3 Original OBD II DLC location requirement.

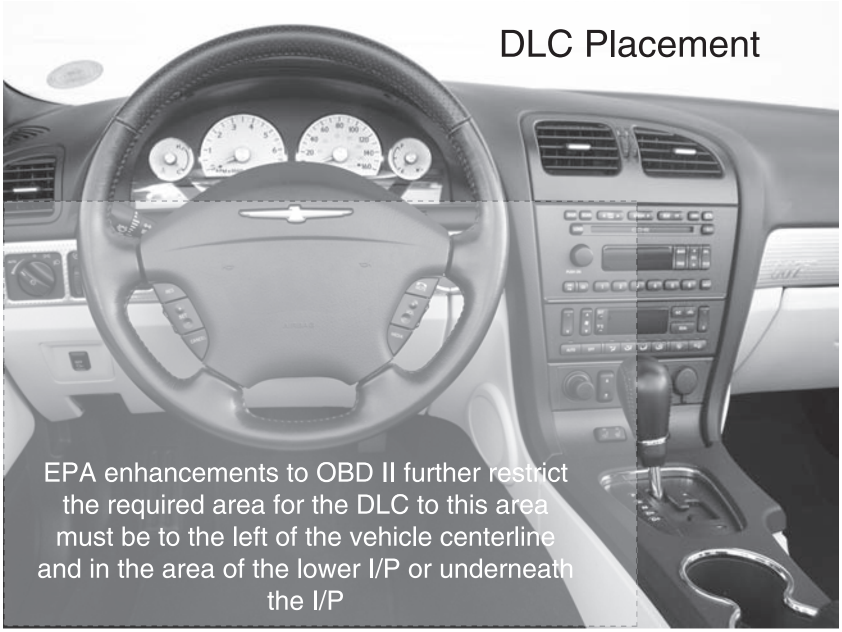

DLC Placement
EPA enhancements to OBD II further restrict the required area for the DLC to this area must be to the left of the vehicle centerline and in the area of the lower I/P or underneath the I/P

Figure 8–4 OBD II DLC location as enhanced by the EPA.

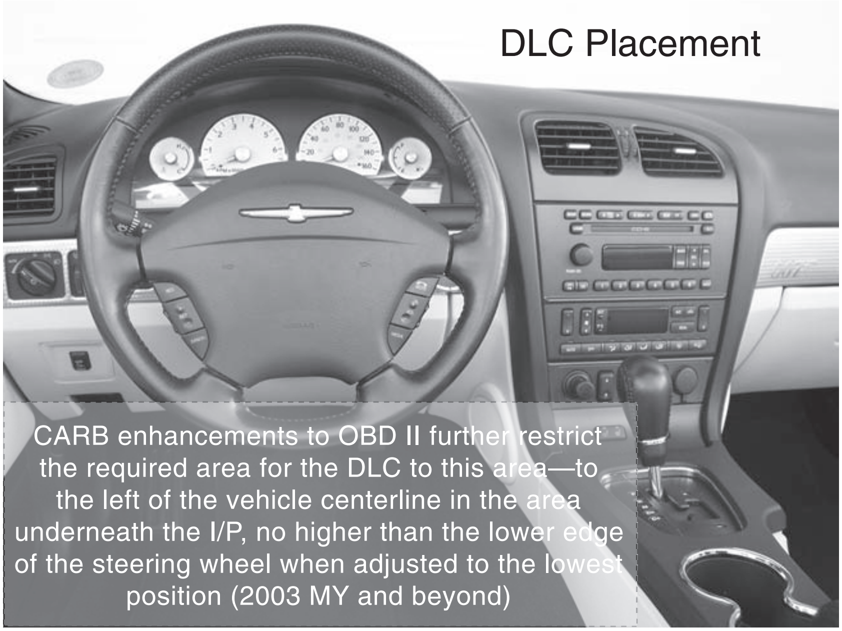

DLC Placement
CARB enhancements to OBD II further restrict the required area for the DLC to this area—to the left of the vehicle centerline in the area underneath the I/P, no higher than the lower edge of the steering wheel when adjusted to the lowest position (2003 MY and beyond)

Figure 8–5 OBD II DLC location as enhanced by CARB.

a specific meaning. The first character is the prefix letter indicating the range of the function:

P = Powertrain
B = Body
C = Chassis
U = Network or Data Link

The second character (the first number) indicates whether the DTC to follow is a standard SAE code or one specific to the manufacturer:

0 = SAE
1 = Manufacturer
2 = SAE
3 = Manufacturer/SAE

SAE-standardized DTCs have the same meaning, regardless of manufacturer, while manufacturer DTCs will have manufacturer-specific meanings. Originally, a “0” was used to identify an SAE-standardized DTC and a “1” was used to identify a manufacturer DTC. Then the “2” was added to identify an SAE-standardized DTC and the “3” was added to identify a manufacturer DTC. However, because the EPA and CARB are pressuring the manufacturers to use fewer manufacturer-specific DTCs and more SAE-standardized DTCs, and because a “4” as the second digit is not considered an option, the majority of P3 codes are SAE-standardized DTCs, with only a few P3 codes being manufacturer-specific, as was originally intended.

The third character of a powertrain DTC (one beginning with P) indicates the system subgroup:

0 = Total system
1 and 2 = Fuel/air control
3 = Ignition system/misfire
4 = Auxiliary emissions controls
5 = Idle/speed control
6 = PCM and inputs/outputs
7 = Transmission
8 = Non-EEC powertrain

The fourth and fifth characters identify the specific fault detected. However, some manufacturers are using a letter value following the fifth digit to increase the number of codes available to the PCM.

Common OBD II Scan Tools (SAE Standard J1979)

OBD II standards mandate that generic, standardized OBD II aftermarket scan tools must be able to access and interpret emission-related DTCs and information, regardless of the vehicle make or model. Most manufacturer-specific and better-quality aftermarket scan tools can communicate with an OBD II PCM in either **VIN Entry Mode** or **Generic OBD II Mode** (the latter being known by at least one aftermarket scan tool manufacturer as **Global OBD II Mode**). These scan tools can also access an abundance of additional information regarding driveability problems, as well as information regarding other vehicle systems. A standardized OBD II aftermarket scan tool will also have a cable and/or an adaptor designed to connect to the OBD II DLC (Figure 8–6).

Hexadecimal. Scan tools communicate with the PCM and the other on-board computers using binary code (see Chapter 2 for an explanation of binary code). In reality, this binary code is converted to **hexadecimal** values for ease in recording information. OBD II scan tools may display some of their available information in the hexadecimal numbering system. Hexadecimal numbering is the process of assigning a single digit to represent four bits of binary code. All binary code, whether 8 bits, 16 bits, 24 bits, 32 bits, or 64 bits, can be subdivided into groups of four bits. Since the decimal (base 10) values for the four columns of binary code are (from right to left) 1, 2, 4, and 8 (Figure 8–7), then having a 1 in each of the four columns would result in a maximum decimal value of 15. Values from 0 through 9 are assigned the single digit 0 through 9 accordingly. For values above 9, the single digit is an assigned letter that represents the decimal value represented by the four bits of binary information, as follows: “A” represents 10; “B” represents 11; “C” represents 12; “D” represents 13; “E” represents 14; “F” represents 15. Therefore, the hexadecimal numbering system is actually a base-16 numbering system containing the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F. Hexadecimal values are generally referred to as “hex codes” and may be identified by a dollar sign ($) in front of the value. Depending upon the scan tool, some of the Generic OBD II modes and their related information will be displayed using hexadecimal numbers; alternatively, many scan tools will translate the related information into decimal values.

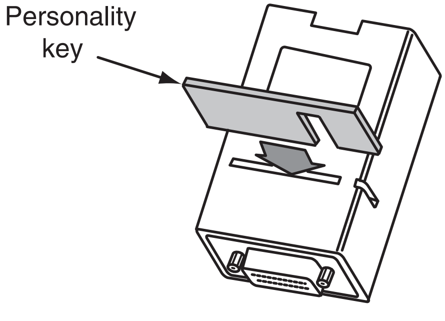


Figure 8–6 The connector of a generic scan tool fits the universal DLC. This aftermarket unit uses plug-in “personality keys” to help take advantage of each manufacturer’s unique proprietary diagnostics, i.e., those that go beyond OBD II.

If, as a technician, you encounter hexadecimal values on your scan tool that you need to interpret, you may do so manually or you may use a scientific calculator. The easiest method is to open the calculator on your desktop or laptop PC. It is available with all Microsoft Windows operating systems and is located under “Accessories.” The first time you open this calculator it is displayed as a standard calculator. Click on “View,” and then click on “Scientific.” A scientific calculator is now displayed that is capable of converting between decimal, binary, and hexadecimal.

If you click on “Dec” (short for “decimal”), you will have a ten-digit keypad displayed (0 through 9) and may enter a value as a decimal value. Follow this by clicking on either “Bin” (short for

Base-10 column values	8	4	2	1	8	4	2	1	8	4	2	1	8	4	2	1
Binary numbers	0	1	1	0	1	1	1	1	0	0	1	1	1	1	0	1
Hex Codes	**6**				**F**				**3**				**D**			

Binary-to-Hex Conversion

Binary		*Hexadecimal Equivalent*	*Binary*		*Hexadecimal Equivalent*
0000	=	0	1000	=	8
0001	=	1	1001	=	9
0010	=	2	1010	=	A
0011	=	3	1011	=	B
0100	=	4	1100	=	C
0101	=	5	1101	=	D
0110	=	6	1110	=	E
0111	=	7	1111	=	F

Figure 8–7 A byte consisting of 16 bits of binary code, subdivided into groups of 4 bits, and then converted to hexadecimal using the conversion chart.

“binary”) or “Hex” (short for “hexadecimal”) for conversion to either of these formats.

If you click on “Bin,” you will have a two-digit keypad displayed (only 0 and 1) and you may enter a value as a binary value. Follow this by clicking on either “Dec” or “Hex” for conversion to either of these formats.

If you click on “Hex,” you will have a sixteen-digit keypad displayed (0 through 9 and A through F) and you may enter a value as a hexadecimal value. Follow this by clicking on either “Dec” or “Bin” for conversion to either of these formats.

So if you see hexadecimal values on your scan tool that you wish to interpret, simply open the Microsoft Windows calculator and enter the value as a hex value. Then click on “Dec” and the decimal value will be displayed.

VIN Entry Mode. When you enable the scan tool to communicate with the on-board computers by entering the VIN information of the vehicle, this is known as “VIN Entry Mode.” Although most diagnosis is commonly performed in this mode, some of the OBD II information is not available in this mode. Also, 2002 model-year and older European vehicles displayed little information in this mode due to the fact that their on-board computer systems were extremely proprietary in design until the EPA forced the issue at a meeting with the manufacturers in June 2001.

Common Generic (Global) Diagnostic Test Modes (SAE Standard J2190)

OBD II reserved 15 generic (global) scan tool requests (or test modes), of which 9 are currently defined. These test modes are common to all OBD II vehicles and can be accessed using an OBD II scan tool. In fact, you have probably used several of these modes without recognizing that you were initializing generic OBD II scan tool requests. Each mode is described in the following paragraphs. Many times, information that is not readily available in VIN Entry Mode is available in Generic OBD II Mode or Global OBD II Mode. For 2002 model-year and older European vehicles, this mode was the best an aftermarket scan tool had to offer. Think of this mode as the "back door access" for data that is not available in the VIN entry mode.

Mode $01—Data Stream and Monitor Readiness Status. Mode $01 is a scan tool request to access both the PCM's data stream and the readiness status of the OBD II monitors.

The data stream allows access to specified data, each identified by a *parameter identification* or PID, as well as the associated values for each PID. For example, PIDs include inputs, outputs, and other data in the PCM's memory. Input PIDs include the TPS, ECT sensor, IAT sensor, MAP or MAF sensor, O_2 sensor, and VSS. The associated values for these PIDs may include both the raw voltage or frequency values for the sensor as well as the interpreted values. For example, if the data stream PID is identified as the ECT sensor, the associated value may include both the voltage that the PCM sees returned from the sensor (example: 0.62 V) and the interpreted value (example: 215°F). Output PIDs include commanded spark timing, commanded fuel injector pulse width, and commands to emission system actuators. The data associated with these PIDs may show commanded spark timing in degrees of crankshaft rotation, fuel injector pulse width in milliseconds of injector on-time, and information about other actuators concerning whether they are commanded energized or de-energized by the PCM. PIDs identifying information contained in the PCM's memory would include short-term fuel trim (STFT) and long-term fuel trim (LTFT) as well as their relative values.

References to PID values exist throughout the automotive service literature. Some of the PID references are from a generic OBD II PID list that all scan tools must be able to reference. Other PID references are for PIDs that can be accessed in the VIN entry mode. Generally, a greater number of PIDs and their respective values can be accessed from VIN entry mode than from the generic mode, but the generic mode ensures that some PIDs can be accessed, regardless of the vehicle manufacturer, when using an OBD II aftermarket scan tool.

This mode also allows an OBD II aftermarket scan tool to check the monitor readiness status of all of the applicable OBD II monitors. Depending upon the scan tool, the results may be displayed as "complete," "done," or "ready" for monitors that have successfully run and "incomplete," "pending," or "not ready" for monitors that have not yet run since the last time codes were erased or the battery was disconnected. Ford PCMs are unique in that they set a DTC P1000 in continuous memory whenever there is at least one monitor that has not run.

Mode $02—Freeze Frame Data Access. Mode $02 is a scan tool request to access emission-related freeze frame data values from specific generic PIDs. These values represent the operating conditions at the time the fault was recognized and logged into memory as a DTC. Once a DTC and a set of related freeze frame data are stored in the computer's memory, they will stay in memory even when additional emissions-related DTCs are stored. The number of such sets of freeze frame data that can be stored is, of course, limited. On General Motors vehicles, for example, the number of such sets is five.

One type of failure is an exception to that rule: misfire. Fuel system misfires will overwrite any other type of data and are not themselves overwritten. They can be removed only with the scan tool. When the scan tool is used to erase a DTC, it automatically erases all the freeze frame data associated with that DTC event.

Mode $03—Read DTCs. Mode $03 is a scan tool request to obtain stored DTCs. Generally, the scan tool will display both the DTC and its descriptive text. The specific menus and access techniques to obtain emissions-related DTCs are left up to the scan tool manufacturer, but such data should be relatively simple to extract. Most aftermarket scan tools are able to access and interpret the manufacturer-specific codes as well. Complete lists of SAE and manufacturers' DTCs are available in aftermarket service manuals.

Mode \$04—Erase DTCs. Mode \$04 is a scan tool request to erase all DTCs. It is actually a PCM reset mode that allows the scan tool to clear all emissions-related diagnostic information from its memory, including DTCs, freeze frame data, and monitor readiness status. Once the PCM has been reset, the PCM may store an inspection maintenance readiness code (for example, Ford's P1000) until all the OBD II system monitors have successfully run.

Mode \$05—Request O_2 Sensor Monitor Test Results. Mode \$05 is a scan tool request for the oxygen sensor monitor test results indicating the on-board sensor fault limits and the actual oxygen sensor voltage outputs during the test cycle. The test cycle includes specific operating conditions that must be met (engine temperature, load, speed) to complete the test. This information helps determine the effectiveness of the exhaust catalytic converter. Here are some, but not all, of the available tests and test identification numbers:

Test ID	Test Description	Units
01	Rich to lean sensor threshold voltage for test cycle	Volts
02	Lean to rich sensor threshold voltage for test cycle	Volts
07	Minimum sensor voltage for test cycle	Volts
08	Maximum sensor voltage for test cycle	Volts

Mode \$06—Request Specific Monitor Test Results. Mode \$06 allows a technician to use a scan tool to request the results of diagnostic tests that are not continuously monitored—for example, the catalytic converter and evaporative system monitors. A technician can use mode \$06 to accurately interpret information as the computer interprets it. This mode can assist the technician in verifying a failure or repair, to understand why the PCM may have blocked a monitor or test, and to identify monitors that may be just within the PCM's set programmed limits but have the potential to fail soon.

Mode \$06 information that is accessed may be represented on the scan tool (depending on the scan tool manufacturer) in a hexadecimal format or a decimal format. Several manufacturers supply mode \$06 charts showing a **test ID (TID),** a **component ID (CID),** and the range of operation that is programmed in the PCM. The manufacturer charts show either a minimum failure value or a maximum failure value, depending upon the TID and CID. These charts are available on some manufacturers' Web sites and, for some manufacturers, are also available on the International Automotive Technicians' Network Web site (http://www.iatn.net). At least one scan tool (OTC Genisys) converts the pertinent values to decimal while, at the same time, displaying the TID and CID numbers in a hexadecimal format (depending on the vehicle that the scan tool is connected to). If your scan tool displays any of these values in the hexadecimal format, use a hex-to-decimal calculator such as the one available with Microsoft's PC Windows operating systems (as described earlier).

The unfortunate thing about mode \$06 on most vehicles is that it can be very challenging to use and interpret the results. Expect the ease of use to improve as OBD II mandates continue to enhance the manufacturers' standards.

Mode \$07—Read Pending DTCs. Mode \$07 allows a technician to use a scan tool to request pending DTCs. Pending DTCs are those codes that have only been identified by the PCM during one **drive cycle** and have not yet been identified as a mature code. Pending DTCs do not result in the illumination of the MIL.

Mode \$08—Active Command Mode. Mode \$08 allows a technician to use a scan tool to activate and deactivate the system's actuators on command. Unfortunately, mode \$08 was never required by either CARB or the EPA under OBD II–standardized guidelines but, rather, was left to the manufacturer's discretion. As a result, most manufacturers allow a generic OBD II scan tool to access relatively few of these active commands compared to a dealership scan tool. One exception to this is Chrysler, whose Actuator Test Mode (ATM), as a very sophisticated example of an active command mode, can be easily accessed with an aftermarket scan tool and can be used to command many output responses of the PCM and several other control modules as well. Chrysler had allowed this accessibility to aftermarket scan tools long before OBD II ever became reality.

As an active command mode, this mode allows the technician to quickly narrow down a problem to either the input side or the output side of the computer by commanding and testing the computer's ability to activate the output on command. For example, if the output actuator does not energize properly during normal driving, but does respond properly during the active command mode, then the technician can rule out the computer and the output as a possible fault, thus narrowing the problem down to the input side of the computer (either a sensor or the sensor's circuitry).

Another function of this mode is that it can make a great component locator. It allows the technician to locate and identify a particular actuator providing the computer can energize it successfully when the command is given. For example, if the cooling fan relay is selected for activation from the scan tool's menu and then one of several relays can be heard (or felt) to be clicking, the technician is able to easily identify exactly which relay is responding to the computer.

Finally, the EPA is working to require that an aftermarket scan tool be able to energize the evaporative system's normally open vent solenoid in order to assist in performing a leak test of this system. While many manufacturers allow this solenoid to be controlled with an aftermarket scan tool, it has not been a requirement in the past.

Mode $09—Read Vehicle-Related Information. Mode $09 is designed to allow a technician to request information regarding the specific vehicle. This information includes items such as the VIN or calibration ID.

MONITORING CONDITIONS

OBD II standards require the engine management system to detect faults, turn the MIL on or off, set DTCs, or erase the DTCs for each monitored circuit according to very specific sets of operating conditions. The following definitions help identify the conditions determined so far:

Warm-Up Cycle

OBD II standards define a warm-up cycle as a period of vehicle operation, after the engine is started in which coolant temperature rises by at least 40°F and reaches at least 160°F. Most OBD II DTCs are automatically erased after 40 warm-up cycles if the failure is not detected again after the MIL is turned off (Figure 8–8). Some manufacturers retain erased DTCs in a "flagged" condition: forgiven, as it were, but not forgotten. This can be useful if the technician notices a pattern of component failure that might be related to a single intermittent cause such as low fuel pressure.

Trip

A **trip** is a key cycle that consists of ignition on, engine run, ignition off, and PCM power down, during which the **enable criteria** for a particular diagnostic test are met and the diagnostic test is run by the PCM (Figure 8–9). A trip is used by the PCM to perform a diagnostic test to confirm a symptom or its repair. If a trip is used by the PCM to confirm a symptom, the PCM responds by setting a DTC in memory if the symptom is still present. A trip can also be used by the PCM to confirm a repair after a DTC has been cleared from the PCM's memory with a scan tool. Because the enable criteria for the various DTCs are different, the required trip used to confirm a symptom or repair for each DTC is also different. Information is readily available that allows the technician to look up the specific enable criteria for any DTC.

Monitor	**Monitor type** (when it completes)	**Number of malfunctions** (on separate drive cycles to set DTC)	**Number of separate consecutive drive cycles** (to light MIL and store DLC)	**Number and type of drive cycles** (with no malfunction to erase pending DTC)	**Number and type of drive cycles** (with no malfunction to turn MIL off)	**Number of warm-ups to erase DTC** (after MIL is extinguished)
Catalyst efficiency	Once per drive cycle	1	3	1	3 OBD II drive cycles	40
Misfire type A	Continuous	1	1		3 similar conditions	40
Misfire type B/C	Continuous	1	2	1	3 similar conditions	40
Fuel system	Continuous	1	2	1	3 similar conditions	40
Oxygen sensor	Once per trip	1	2	1 trip	3 trips	40
EGR	Once per trip	1	2	1 trip	3 trips	40
Comprehensive component	Continuous when conditions allow	1	2	1 trip	3 trips	40

Figure 8–8 OBD II DTC/MIL function chart.

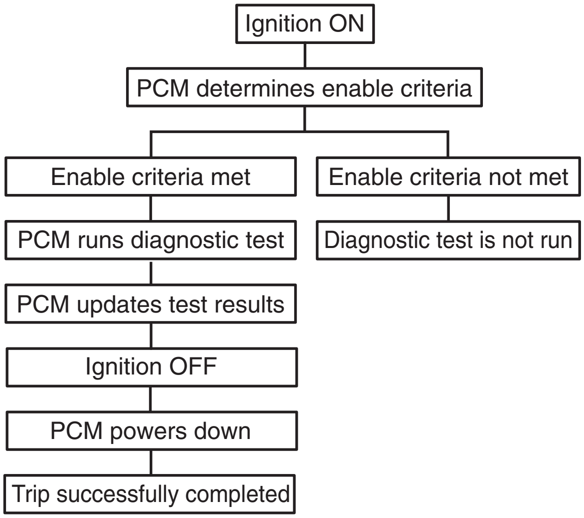


Figure 8–9 An OBD II trip.

Drive Cycle

A drive cycle is a series of operating conditions that allows the PCM to complete all of the OBD II emissions-related monitors (Figure 8–10). When all of the driving conditions or enabling criteria have been met and, therefore, all of the diagnostics have been run, the system is said to be inspection/maintenance (I/M) ready and all of the electronic I/M “flags” in the PCM are set to “yes.” An OBD II scan tool may be used to determine whether system diagnosis is complete and, if not, which I/M “flags” are not yet set to “yes.” The scan tool is only able to determine which diagnostics have not yet been run and thus are still needed to complete the full drive cycle. A scan tool does not generally identify specifically the outcome of each test, except, of course, for

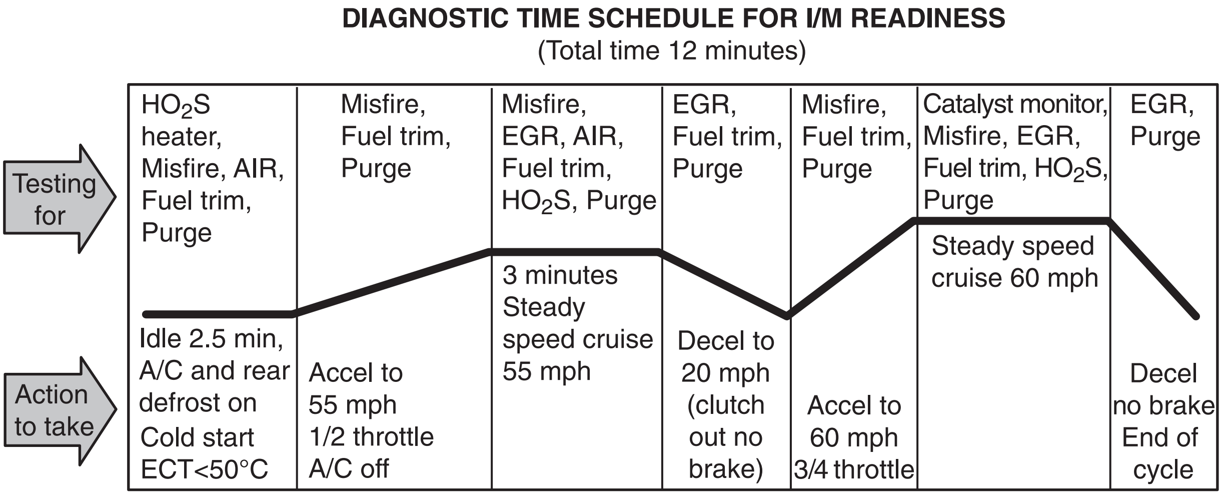

DIAGNOSTIC TIME SCHEDULE FOR I/M READINESS
(Total time 12 minutes)
Testing for
Action to take
HO2S heater, Misfire, AIR, Fuel trim, Purge
Misfire, Fuel trim, Purge
Misfire, EGR, AIR, Fuel trim, HO2S, Purge
EGR, Fuel trim, Purge
Misfire, Fuel trim, Purge
Catalyst monitor, Misfire, EGR, Fuel trim, HO2S, Purge
EGR, Purge
Idle 2.5 min, A/C and rear defrost on Cold start ECT<50°C
Accel to 55 mph 1/2 throttle A/C off
3 minutes Steady speed cruise 55 mph
Decel to 20 mph (clutch out no brake)
Accel to 60 mph 3/4 throttle
Steady speed cruise 60 mph
Decel no brake End of cycle

Figure 8–10 General Motors OBD II drive cycle.

DTCs that have been set in the PCM's memory. (The exception to this is the "Mode 6" capability of the scan tool. In this mode the scan tool is able to tell the technician the results of several tests, depending upon the vehicle manufacturer.)

The diagnostic conditions that make up a drive cycle may be run in any order. As the PCM sees each diagnostic condition achieved, it runs the associated monitors. Drive cycle diagnostic conditions and requirements vary among manufacturers. A pre-1998 General Motors drive cycle is shown in Figure 8–10. It requires 12 minutes to run the entire drive cycle. In 1998, General Motors lengthened its drive cycle to a total of 19 minutes.

Similar Conditions

Once the MIL has been turned on for misfire or a fuel system fault, the vehicle must go through three consecutive drive cycles, including operating conditions similar to those existing at the time the fault was first detected, to turn the MIL off. Similar conditions mean:

- engine speed within 375 RPM of the DTC flagged condition
- engine load within 10 percent of the DTC flagged condition
- engine temperature the same (either cold or warmed up)

Note that with most OBD II faults, it is necessary for a circuit to fail twice to set a DTC that turns on the MIL. Notice also that achieving operating conditions similar to those when the DTC was first set could take some time, particularly if the conditions are unusual. If the problem initially appeared only at WOT and high RPM, these conditions may not be met again until the next time Granny borrows the car.

SETTING DTCs AND TURNING ON THE MIL

Class A DTCs

A class A code is a DTC that will result in the immediate illumination of the MIL. This type of code sets in response to a gross emission failure. For example, the misfire monitor can store a DTC and start flashing the MIL in response to its first detection of a type A misfire.

(A type A misfire is classified as a severe misfire that could result in the overheating of the three-way catalytic converter [TWC], resulting in converter damage.)

Class B DTCs

Most DTCs are class B codes. With this type of code, when an emissions-related fault is detected for the first time, a DTC for that fault is stored as a pending or intermittent code. Different manufacturers describe this preliminary code differently. Ford calls it a "pending" code; Chrysler calls it a "maturing" code; and General Motors calls it a "failed last time" code. Whatever the name, during the next trip or drive cycle the pending fault will be erased if the monitoring sequence that first detected the fault is repeated and the same fault does not recur. If the fault does recur on the second trip or drive cycle, a mature DTC is stored (as a "history" code in General Motors language) and the computer turns on the MIL.

Class C DTCs

A class C code is a DTC that results in illumination of a "Service Engine Soon" light and not the MIL itself. These codes are the least critical of the code types.

Turning Off the MIL

Different faults must meet different criteria for turning the MIL on or off. If the MIL was turned on by a monitoring sequence for a heated oxygen sensor, the EGR, or the total system, it will turn off after three consecutive OBD II trips during which the problem does not recur under the expected circumstances. If a misfire or fuel mixture monitoring sequence detected the fault, it will be turned off after three repeated OBD II trips with similar conditions met without the problem reappearing. Similarly, an MIL illumination that resulted from a fault detected in the catalytic converter effectiveness monitoring sequence will also be automatically turned off after three OBD II trips with the proper conditions met but without recurrence of the fault. Turning the MIL off, however, does not automatically erase the stored DTC.

Erasing of a DTC

Erasing a DTC requires 40 warm-up cycles without the problem recurring, counting from the first cycle after the MIL is turned off. DTCs can also be erased by a technician using a scan tool.

DIAGNOSTIC MANAGEMENT SOFTWARE

Each PCM includes diagnostic management software to organize the complex testing procedures. The terms used for this diagnostic management software vary by manufacturer. Ford and General Motors call theirs the "diagnostic executive," while Chrysler calls it the "task manager."

Each monitoring sequence performs its tests under a particular set of operating conditions, or enabling criteria, including specific temperature, engine speed, load, throttle position, and time duration from startup. These conditions must be met for the test to be completed. The diagnostic management software determines the sequence in which the tests will be run, whether the proper conditions have been met for each test, and whether the duration of the test was sufficient. If not, the test is aborted, and that trip is not counted for the test being performed; instead, the managing software waits for the next opportunity to run the appropriate monitoring sequence.

As an example, let us say an EGR monitoring sequence has detected a fault on a given trip. A pending DTC has been set, and the diagnostic management software is waiting for the next trip to confirm the fault (and store the DTC and light the MIL) or to confirm correct functioning of the system and erase the pending DTC. During the next period of vehicle operation, the software waits for engine data indicating the correct enabling criteria have been met, including engine temperature and idle speed, with over 4 minutes since startup. If these conditions have been met, the software begins the EGR monitoring sequence, testing the EGR system. Suppose there have been enough idle time and the correct amount of acceleration, followed by a steady throttle position at 34 MPH for well over a minute. Then let us assume 5 minutes of driving at speeds from 23 to 44 MPH, but no WOT operation, followed by unbraked deceleration and idle for 15 seconds. Then the ignition is turned off.

A trip (the minimum for an EGR monitoring sequence test) has not occurred yet because there was no half-throttle acceleration to 55 MPH. The EGR system has neither passed nor failed the second test; the diagnostic management software is still waiting for the next trip so the test can be run again. This sequence included a long enough drive cycle, however, to enable the misfire and fuel system monitoring sequences to complete their tests.

Sometimes the diagnostic management software may cancel a test because of an additional problem with significant connection to the test circuit. For example, if the computer already knows the oxygen sensor is not working, it will not conduct a monitoring sequence test of the catalytic converter or the evaporative system because the results would be meaningless. That test will be postponed until the oxygen sensor circuit problem is corrected and the correction is recognized by the computer.

Sometimes the computer will not run a given test because it conflicts with some other test currently underway. For example, if the computer is running the EGR monitoring sequence, it will not run the catalytic converter monitoring sequence at the same time. When the EGR test is in progress, the variations in EGR gas temporarily cause conditions in the catalytic converter that are not representative of normal converter operation.

Freeze Frame Data

Besides storing detected DTCs, the diagnostic management software keeps a record of all the relevant engine parameters for a given circuit. If a fault is detected and recorded, that information is stored as a **snapshot.** This data, known as *freeze frame data,* is used by the diagnostic management software for comparison and identification of similar operating conditions when they recur. The data is also available to the diagnostic technician for further information about what might be amiss in the system. The technician may also use the freeze frame data to aid in duplicating the symptom during a road test. This information can be accessed with the scan tool. Freeze frame information typically includes the following:

- the DTC involved
- engine RPM
- engine load
- fuel trim (short and long term)
- engine coolant temperature
- MAP and/or MAF values
- operating mode (open or closed loop)
- vehicle speed

The freeze frame data storage capacity for OBD II is required to store only one freeze frame for a DTC, though some manufacturers have chosen to install greater capacity (five in GM's case). On the basic system, freeze frame data is stored only for the DTC that occurred first, unless a later DTC is of higher priority, such as a severe misfire or fuel system DTC. In that case, the diagnostic management software replaces the stored data from the lower priority DTC with the freeze frame data related to the misfire or fuel system DTC.

OBD II MONITORS

As mentioned previously, a monitoring sequence, generally called simply a *monitor,* is an operating strategy the computer uses to check the operation of a specific circuit, system, function, or component. Some of the specific monitoring sequences commonly used are described in this section.

One type of monitor is one that is monitored continuously whenever the vehicle is operating and is therefore known as a **continuous monitor.** Another type, known as a **non-continuous monitor,** requires the PCM to energize/de-energize specific output actuators, not because of engine/vehicle requirements, but specifically to test the monitor so that the resulting change in conditions can be measured. This is commonly known as an **intrusive test.** An intrusive test is a system/component test initiated by the PCM, although, in concept, it is similar to a self-test (described in Chapter 5) that may be initiated by a technician. The driver may even feel an intrusive test as the PCM performs it.

Catalyst Efficiency Monitor

As the engine's fuel system cycles from slightly lean to slightly rich in response to the oxygen sensor signal, an effective TWC stores some oxygen during the lean cycles and uses that oxygen to oxidize (burn) the excess hydrocarbons and oxidize the carbon monoxide during rich periods. Because of this phenomenon, the percentage of oxygen in exhaust discharged from the converter tends to be nearly constant despite fluctuations in the amount entering. An effective converter will even this out, but one that has begun to lose its capacity to store oxygen will not be able to do so; therefore, its downstream oxygen signal will begin to fluctuate with the oxygen content entering, just as the upstream sensor does (Figure 8–11).

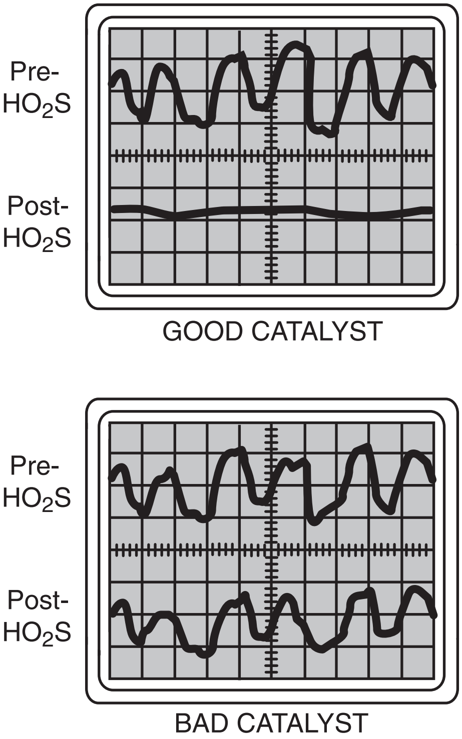


Figure 8–11 There is a difference between the voltage signals of the two oxygen sensors if the catalytic converter is operating efficiently, but the signal from the rear O_2 sensor will start to fluctuate along with the front sensor if the catalyst is deteriorating.

Catalytic converter effectiveness is tested once per OBD II drive cycle, and this test is conducted by comparing the readings of the downstream (rear), post-cat oxygen sensor (sometimes called the *catalyst monitor sensor* [CMS]) with the signals from those in front of the converter (pre-cat sensors). As the PCM commands the fuel mixture to be rich and lean across the stoichiometric value, the upstream oxygen sensors should produce a rising and falling voltage signal in response to the residual oxygen leaving the combustion chambers. The downstream sensor (CMS) should produce a signal of much lower frequency and amplitude, as shown in Figure 8–11. To prevent mix-ups, the downstream sensor has a different harness connector than the pre-cat sensor, though operation of the two sensors is identical.

In reality, while the previous description is technically correct for proper understanding on the part of the technician, the difference in the waveforms of the two sensors when comparing those of a converter with good efficiency to those of a converter that is just inefficient enough to fail OBD II standards (resulting in a "cat efficiency" DTC) may be minuscule. It is therefore not advisable for a technician to attempt to use these waveforms to test converter efficiency directly.

The PCM is programmed to look for particular differences in the waveforms that might be misinterpreted by a technician.

Also, manufacturers are using pre-cat and post-cat O_2 sensors to monitor the efficiency of NO_x reduction catalytic converters. The NO_x reduction converter uses CO to break up NO_x, thus releasing oxygen. The effect of this chemical reaction on exhaust oxygen content has been programmed into the PCM so that the PCM can determine the efficiency of the NO_x reduction bed as well as that of the CO/HC oxidation bed.

Misfire Monitor

Any time a cylinder misfires, the raw fuel and air are pumped from that cylinder into the exhaust and through the catalytic converter. With this much oxygen and fuel dumped into and burned in the catalytic converter, it gets very hot. The ceramic or aluminum-oxide honeycomb may begin to melt into a solid mass, ceasing emissions functions and plugging the exhaust with a molten lump. Emissions performance and driveability both suffer dramatically.

Misfires are therefore monitored continually by measuring the contribution of each cylinder to engine speed. This is referred to as **misfire detection.** As the engine runs, the crankshaft speed is not actually constant but changes slightly as each cylinder delivers torque during its power stroke. Between power strokes, the crankshaft actually slows down by a few RPM, only to reaccelerate with the next cylinder's power stroke. By using a high data rate crankshaft position (CKP) sensor, manufacturers can provide the computer with a means to track these slight variations in engine RPM. When it does not detect the appropriate acceleration for a given cylinder (identified by the CKP sensor, in some cases comparing with data from the camshaft position [CMP] sensor), the computer knows that cylinder has misfired.

Even in engines that are running perfectly, combustion is not perfect, and there are occasional misfires. Misfires that are severe enough to raise catalytic converter temperatures to more than 1800°F are regarded as type A misfires. Type B misfires are those that could cause emissions to increase to more than 1.5 times the FTP standard, while type C misfires could cause a vehicle to fail a state emissions test. Most OBD II PCMs allow a misfire rate of somewhere between 1 percent and 3 percent at idle before a type B or C misfire fault is stored but may allow a misfire rate as high as 40 percent at idle before a type A misfire fault is stored. However, under high load and RPM conditions, a type A misfire fault will be stored if the misfire rate exceeds 4 percent. This is because, as the load and RPM are increased, it takes a lower misfire rate to create the potential for overheating the catalytic converter.

The OBD II misfire monitoring sequence includes an adaptive feature compensating for variations in engine characteristics caused by manufacturing tolerances and component wear, as well as the adaptive capacity to allow for vibration at different engine speeds and loads. When an individual cylinder's contribution to engine speed falls below a certain threshold, however, the misfire monitoring sequence calculates the vibration, tolerance, and load factors before setting a misfire DTC. Also, on some applications, the PCM receives input from the antilock brake system's wheel speed sensors to determine when perceived cylinder misfire is simply the result of drive train influences due to a rough road surface.

Type A Misfire Monitoring Sequence. If, during 200 revolutions of the crankshaft, the misfire monitoring sequence (Figure 8–12) detects a misfire rate that would cause the catalytic converter temperature to reach 1800°F or above, the MIL begins to flash and the system defaults to open loop to prevent the fuel control system from commanding a greater pulse width (because of the extra oxygen in the exhaust stream from the misfired cylinder). Once the engine is out of the operating range in which the high misfire occurs, the MIL stops flashing but stays on constantly. A DTC is immediately set. Many manufacturers whose products use sequential fuel injection have programmed the PCM to turn off one or two injectors associated with the faulty cylinders, to

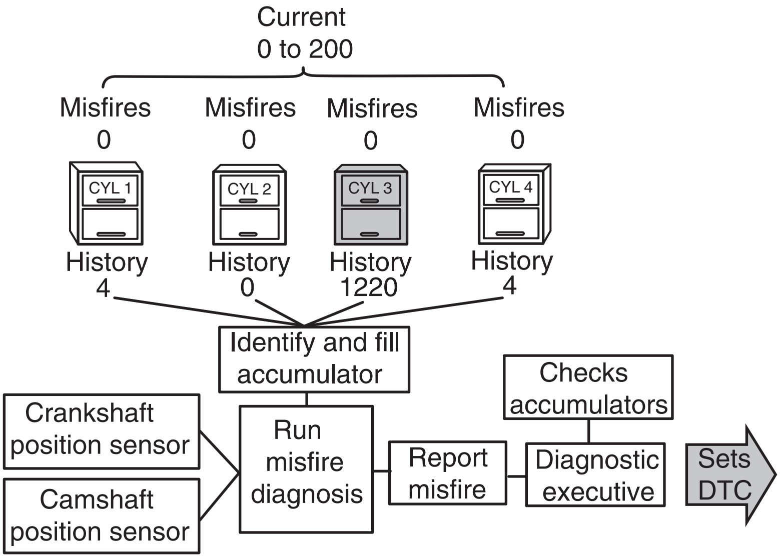


Figure 8–12 Misfire counters are similar to files kept on each cylinder. Current and historical misfire counters are maintained, and the diagnostic executive reviews this information before setting a DTC.

keep from pumping fuel into the exhaust. As a safety exception, however, if the engine is under load, as when passing or climbing a hill, the PCM does not deny fuel to the misfiring cylinder or cylinders.

Type B/C Misfire Monitoring Sequence. If, during 1000 revolutions of the crankshaft, the misfire monitoring sequence detects a misfire rate of 1 to 3 percent, it sets a pending DTC and records all the operating conditions at the time as freeze frame data. If the same pattern is repeated on the next drive cycle, the diagnostic management software turns on the MIL.

Fuel Trim Monitor

Though this is one of the highest-priority monitoring sequences, it is also one of the simplest. Whenever the system is running in closed loop, the fuel system monitoring sequence continuously watches short-term fuel trim (STFT) and long-term fuel trim (LTFT).

If a problem such as a vacuum leak, air flow restriction, or incorrect fuel pressure causes the adaptive fuel control to make changes exceeding a predetermined limit in the STFT or LTFT, the fuel system monitoring sequence reports a failure, and a pending DTC is set. On the next drive cycle, if the failure does not reappear, the pending code is erased; if it does appear again, a mature DTC is set and the MIL is turned on.

Fuel trim that is operating inside of a plus or minus 15 percent window can be considered quite normal, depending upon the manufacturer. Fuel trim values that exceed plus or minus approximately 30 percent will usually set a DTC. This is because as the fuel trim adjustment becomes too great, the PCM loses its ability to accurately control the air/fuel ratio to around 14.7:1, thus allowing exhaust emissions to greatly increase.

Oxygen Sensor Monitor

The monitoring sequence tests upstream and downstream oxygen sensors separately, testing each once per drive cycle. Once the diagnostic management software identifies the correct engine operating conditions, the computer pulses the injectors at a fixed pulse width to drive the O_2 sensors both rich and lean. The oxygen sensor monitoring sequence checks the frequency of the oxygen sensor signal to see that it produces a signal corresponding to the pulse width of the fuel injectors. The frequency is high enough that a slow-responding oxygen sensor is not able to keep up and exhibits a reduced amplitude sign as well. To pass the oxygen sensor monitoring sequence, the oxygen sensor must generate a voltage output greater than 800 mV when the air/fuel ratio is rich, fall below 175 mV when the air/fuel ratio is lean, switch across 450 mV a minimum number of times during a 120-second period, and demonstrate a rapid voltage rise and fall, known as *response time.* An O_2 sensor's response time must show that the sensor can switch between 300 mV and 600 mV in each direction in less than 100 ms.

Because of the way the catalytic converter works, the rear oxygen sensor (the CMS) should normally produce a low amplitude and a fairly low frequency signal. During CMS testing, the computer forces the air/fuel ratio from rich to lean to force the CMS to produce higher amplitudes. If a rich air/fuel condition is momentarily sustained going into the combustion chambers, available stored oxygen in the catalytic converter is consumed, and the converter will contain less oxygen. In consequence, the CMS signal should go higher in voltage. If a lean condition is then momentarily sustained, the converter gets saturated with oxygen and the CMS signal should drop in voltage.

Certain automotive manufacturers use gold-plated pins and sockets for the oxygen sensor harness connector to obtain increased reliability and to meet the extended period of emissions warranty required by the law.

Oxygen Sensor Heater Monitor

The PCM's programmed procedures to monitor the heaters (and their controlling circuits) associated with the exhaust gas oxygen sensors (including both the primary O_2 sensors ahead of the converters and the post-cat O_2 sensors) differ among manufacturers.

Ford, for example, uses the PCM to actuate the heater circuits. In this case it is easy to monitor whether the circuit is working by monitoring the circuit voltage.

General Motors handles the testing differently. In these vehicles, the PCM feeds a bias voltage of approximately 0.45 V to the heated oxygen sensor (HO_2S) signal terminal. When the oxygen sensor reaches operating temperature and starts to generate a signal, the bias voltage is turned off and the system works normally. When the ignition is turned on, it feeds battery voltage to the front oxygen sensor heater circuit, which has a fixed ground. After a cold start the PCM measures how long it takes for the forward oxygen sensor to start generating signals. The sensor, of course, reaches operating temperature faster with the heater circuit energized. If the PCM determines from its memory that it took too long to start generating mixture feedback signals, a pending DTC is set. The amount of time allowed for the sensor to start producing signals depends on the ECT and IAT temperature signals.

Chrysler uses yet another strategy to test the front oxygen sensor heater circuit. The heater is powered directly by the automatic shutdown (ASD) relay, controlled by the PCM. After the ignition is shut off, the PCM uses the battery temperature sensor to sense ambient temperature. It then waits for a specific time, based on the ambient temperature, for the oxygen sensor to cool down long enough to stop generating any signal. After that time, the PCM energizes the ASD relay. If the heater brings the oxygen sensor back to operating temperature, it resumes generating a signal, even though the engine is not running. If the sensor does not produce a signal within a predetermined amount of time, a pending DTC is set.

EGR System Monitor

Different manufacturers use different methods to obtain EGR system feedback, to confirm that the system is working under engine conditions in which it is needed. One of the simplest methods is the one used by Chrysler.

In normal operation, when the EGR valve opens, the pulse width to the injectors is somewhat reduced to compensate for the oxygen displaced by the inert exhaust gas. Chrysler's strategy is to select an operating condition that meets the test criteria, including the criterion that the EGR valve should open. Then, without any other change in the pulse-width command to the injectors, the EGR valve is disabled and closed. This should cause the air/fuel ratio to go lean, since there is, in effect, more oxygen in the mixture. Monitoring the oxygen sensor signal and the resulting STFT values thus indicates the proper (or improper) function of the EGR valve. There are other strategies, which are covered in the appropriate manufacturer-specific chapters of this textbook.

Comprehensive Component Monitor

The remaining inputs and outputs affecting emissions may not be individually tested by a monitoring sequence. They are instead checked by the comprehensive component monitor (CCM). In many cases, monitoring these components is done in the same way it was on earlier systems (Figure 8–13). Inputs are checked for open circuits and shorts, and their information is compared against each other. For example, the PCM may compare the TPS value against engine load as reported by the MAP or MAF sensor. Or it may compare the ECT value against that of the IAT. This is known as **rationality testing** or **efficiency monitoring.** Another rationality test involves energizing an actuator while watching a pertinent input. That is, the PCM may use the IAC solenoid valve or stepper motor to adjust the engine's idle speed while it watches the tach reference signal for an equivalent change in frequency. Or, with the fuel pump relay commanded to be energized, it may watch for source voltage to be returned on the fuel pump monitor (FPM) circuit.

Digital and frequency input signals are checked by plausibility. Again, this is done by using other sensor values and calculations to determine whether a given sensor's reading is approximately what would be expected for the existing conditions. For example, the diagnostic management software compares the CKP signal to the CMP signal. Some examples of these interrelated signals are:

- crankshaft position (CKP)
- camshaft position (CMP)
- vehicle speed sensor (VSS)
- transmission output shaft speed (OSS)

Important: Not all vehicles have these components.

Components Intended to Illuminate MIL
Automatic transmission temperature sensor
Engine coolant temperature (ECT) sensor
Evaporative emission canister purge
Evaporative emission purge vacuum switch
Idle air control (IAC) coil
Ignition control (IC) system
Ignition sensor (cam sync, Diag)
Ignition sensor Hi res (7X)
Intake air temperature (IAT) sensor
Knock sensor (KS)
Manifold absolute pressure (MAP) sensor
Mass airflow (MAF) sensor
Throttle position (TP) sensor A and B
Transmission 3/2 shift solenoid
Transmission range (TR) mode pressure switch
Transmission shift solenoid A
Transmission shift solenoid B
Transmission TCC enable solenoid
Transmission torque converter clutch (TCC) control solenoid
Transmission turbine speed sensor (HI/LO)
Transmission vehicle speed sensor (HI/LO)

Figure 8–13 By the CARB regulations, comprehensive component monitoring will illuminate the MIL if there is a failure in any of these components.

Output State Monitor. The output state monitor, or OSM, is actually a part of the CCM. It tests other outputs and actuators for opens and short circuits by monitoring the voltage in the actuator's driver circuit. A circuit is added within

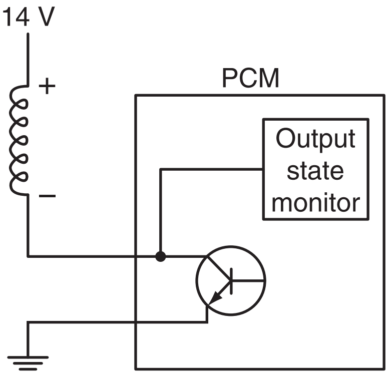


Figure 8–14 OSM voltage sensing circuit.

the PCM that tests the voltage potential between the actuator and the driver (Figure 8–14). Whenever the actuator is not energized, the voltage on the ground side of the actuator, but before the driver, should be at the charging system voltage. If not, the PCM knows that there is an open in the circuit ahead of that point. If this test passes, the PCM will energize the actuator by forward biasing the driver, thus completing the circuit to ground. This pulls the voltage to near zero volts. If this test fails, the PCM knows that the driver is faulty. The following are actuators typically monitored by OBD II systems:

- idle air control coil
- EVAP canister purge vacuum switch
- fan control (high speed)
- heated oxygen sensor heater (HO_2S)
- catalytic converter monitoring oxygen sensor (CMS)
- wide-open throttle air-conditioning cutout (WAC)
- electronic pressure control (EPC) solenoid
- shift solenoid 1 (SS1)
- shift solenoid 2 (SS2)
- torque converter clutch (TCC)

Faults in the last four of these actuator circuits most frequently result in the PCM turning on the transmission control indicator light (TCIL) rather than the MIL, if there is such a light on the vehicle.

Canister Purge and Evaporative System Monitor

The PCM uses this monitor to test two things: whether the canister purge system is able to properly purge the hydrocarbons from the charcoal canister and whether the evaporative system and fuel tank are able to keep hydrocarbons from being released into the atmosphere.

Initially, OBD II standards required that the PCM have the capacity to test the purging potential of the canister purge system. Two methods were used. One method involved using a purge flow sensor in the purge line immediately after the purge solenoid. Ford Motor Company used an NTC thermistor that measured the cooling effect of the flow of the hydrocarbon vapors as the PCM commanded the purge solenoid to open. The other method used no additional sensors but, rather, allowed the PCM to wait until the oxygen sensors were active and then commanded the purge solenoid to open. The PCM would then watch the STFT values to see if the supposed purging of the charcoal canister was actually causing the air/fuel ratio to go rich.

Early on in the OBD II program, the standards were enhanced to require the PCM to monitor the evaporative system and the fuel tank for leaks that could allow unburned hydrocarbons to reach the atmosphere. This enhanced system adds a PCM-controlled vent solenoid (normally open) to the atmospheric side of the charcoal canister, in addition to the normally closed canister purge solenoid in use on most systems (Figure 8–15). A pressure sensor is mounted at the fuel tank (usually part of the sender and fuel pump assembly). Depending on the manufacturer, either a vacuum may be drawn on the fuel tank (most manufacturers) or an air pump may be used to pressurize the fuel tank (Chrysler and some European vehicles) to test for leaks. The vacuum method is described here.

Testing the OBD II system begins when the charcoal canister is charged when the vehicle is parked. The concrete, asphalt, gravel, or dirt the vehicle is parked on has absorbed heat from the sun's rays. The warm surface of the parking pad

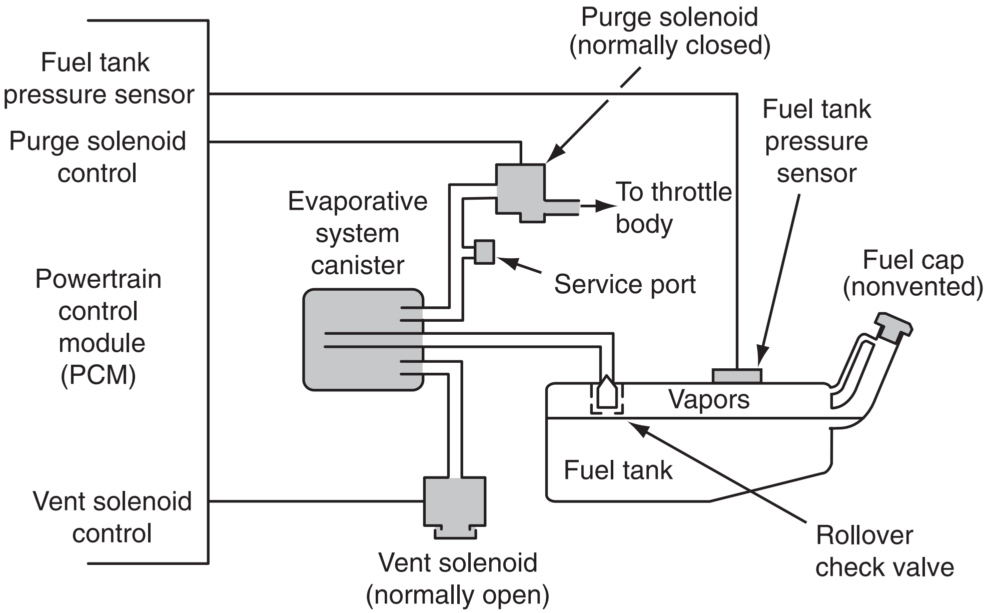

Fuel tank pressure sensor
Purge solenoid control
Powertrain control module (PCM)
Vent solenoid control
Purge solenoid (normally closed)
Evaporative system canister
To throttle body
Service port
Fuel tank pressure sensor
Fuel cap (nonvented)
Vapors
Fuel tank
Rollover check valve
Vent solenoid (normally open)

Figure 8–15 Evaporative system components.

causes heat to rise to the bottom of the fuel tank and warms the fuel inside. The close proximity of the exhaust pipe adds to this heat radiation. Fuel absorbs heat during the evaporation process through a process similar to air-conditioning heat transfer—that is, when heat is transferred into a liquid, the liquid changes into a gas. The gas then contains the heat. There is only one way the expanded gas can leave the tank. It must go through the charcoal canister and the normally open computer-controlled vent valve. Fuel vapors travel through the activated charcoal of the canister, where they are absorbed. This means that only heated air is permitted to vent. This cycle completes the charging process.

Charging does not occur on extremely cold days. The computer knows the outside temperature and compensates for it. The test schedule is modified by the computer, or may not be completed at all, if the fuel tank level is over 80 percent or under 15 percent. The tank sender unit provides fuel level information to the computer. In earlier systems, it was merely a sensor for the instrument cluster.

To begin the test, turn the key but do not start the engine. This puts the normally open vent valve in the de-energized position. The computer should be able to sense atmospheric pressure in the fuel tank. The computer checks the fuel tank pressure sensor against the intake manifold pressure sensor. Both should read the same atmospheric value. If the values differ, the computer must decide which sensor has an incorrect reading. It does this through comparison. The two readings are compared against the computer's memory of the last 50 startups. Deviations from these memory parameters cause the computer to set a code. The computer can install a default value for intake manifold pressure sensor failure.

The computer opens the normally closed EVAP solenoid when the engine reaches normal operating temperature. The opened EVAP solenoid allows engine vacuum to pull fuel vapors from the charcoal. The computer uses the oxygen sensor to monitor the exhaust. *Cross-counts* are the number of times the oxygen sensor switches from a rich air/fuel mixture to a lean air/fuel mixture within a specific period of time. The cross-counts should indicate a sudden richness in the air/fuel mixture. If this richness is not indicated, the computer assumes that either the charcoal canister was not charged properly or that the charcoal lost its charge. Charcoal charge may be lost when the fuel tank cap is left off. It may also be lost if there is a leak in one of the fuel hoses. The computer does not run further tests unless it senses that the charcoal canister was not charged.

The next test has a relatively short cycle. It is called a *gross* or *large leak test.* The computer energizes the normally open vent solenoid valve to close it. Then it simply energizes the normally closed EVAP purge solenoid valve to open it and allows intake manifold vacuum to be drawn on the charcoal canister. If the computer detects engine vacuum inside the fuel tank, it must act rapidly because if this vacuum draw continues for too long, it will cause the fuel tank to collapse. If the computer does not detect a vacuum, it suspects a gross leak or a pinched hose leading to the tank. If the computer detects a vacuum, it assumes the charcoal canister charge must have leaked out through a very small hole. The computer then runs the next test.

This test is called the *small leak test.* For the small leak test, the computer energizes both solenoid valves as in the gross leak test, and then it de-energizes the EVAP solenoid valve, thus closing both valves. This traps intake manifold vacuum inside the fuel tank. The computer monitors how long the tank holds this vacuum. If the vacuum leaks out within a predetermined time, the computer has discovered a small leak. If the vacuum does not leak out and the ambient air temperature is insufficient to charge the canister, the computer finds no leak and decides the system is operating properly.

From 1996 through model year 2000, the PCM had to allow the fuel tank to hold this vacuum long enough to verify that no leaks were present that exceeded 0.040 in. Beginning in 2001, the PCM was required to identify any leaks larger than 0.020 in.

The most common problem found with this system is caused by the owner of the vehicle, who might fail to tighten the fuel filler cap properly. Although the computer does not detect this at the time of refueling, when the vehicle is started the next morning, the computer discovers a leak, turns on the check engine light in the dashboard instrument cluster, and stores a code. The owner then returns the vehicle to the dealership for service.

Secondary Air (AIR) Monitor

Manufacturers are permitted to use a variety of methods to monitor the air injection system, provided they detect increases of 1.5 times allowable emissions. The most common method is to first test the solenoid valves electrically, using the OSM's ability to test ground side voltage while energizing and de-energizing the solenoid. Then the PCM commands the air flow to switch between upstream and downstream, or as applicable, to switch between upstream and an atmospheric dump (belt-driven systems) while using the primary oxygen sensors to detect the air flow each time it is switched to the upstream position. While most vehicles built to the OBD II standards in 1996 no longer employ an air injection system, those that do are able to monitor its function with the primary oxygen sensors.

Chlorofluorocarbon Leakage Monitor

While the OBD II standards require the monitoring of chlorofluorocarbons (CFCs), other federal laws prohibit the production of the product, so no vehicles will actually continue to employ this type of refrigerant. Because there are no CFCs, there is no requirement to monitor them.

On-Board Refueling Vapor Recovery (ORVR) System

Another federal mandate requires vehicles to capture any vapors that arise during refueling. The refueling process begins with a spring-loaded, closed, anti-spit-back valve, which is located at the bottom of the fuel tank filler tube.

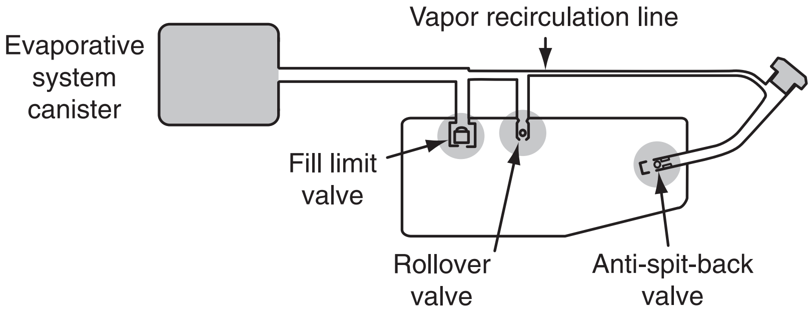


Figure 8–16 ORVR system components.

The filler tube is designed like the venturi area of a carburetor. The filler pipe diameter is reduced to 24 mm, or approximately 1 inch. When fuel travels down this small pipe, it produces a liquid seal that prevents the escape of fuel vapors from the tank during refueling. Vented fuel vapors in the vapor recirculation line are drawn back down the filler pipe by the venturi action of the pipe (Figure 8–16).

As the fuel tank fills, the fill limit valve rises. This causes the passageway to the charcoal canister to close and prevents liquid from overcharging the canister. Liquid in the tank rises up the filler neck and shuts off the automatic gas pump nozzle.

COLD START EMISSIONS REDUCTION

During warm-up from a cold start, an engine will normally emit a much larger percentage of toxic emissions than it does once it is warm and in closed loop. To reduce cold start emissions, a couple of different strategies are currently used.

Ignition Timing Retard

Beginning in the late 1990s (Ford in 1998), manufacturers began programming their PCMs to retard ignition timing during engine warm-up from a cold start. By beginning combustion slightly later, more waste heat is generated, thereby increasing the temperature of the engine more quickly. The amount of spark timing retard is from as little as 2 degrees retarded (General Motors) to as much as 20, or even 25, degrees.

Strategy Changes for Entering Closed Loop

Another strategy to reduce cold start emissions is to get the engine into closed loop as quickly as possible. You might recall (see Chapter 1) that the manufacturers' initial criteria for entering closed loop were as follows:

- The oxygen sensor must reach operating temperature.
- The ECT sensor must indicate that the engine is warmed up to at least 150°F. (This was a typical value, but some manufacturers even had some late 1980s PCMs that required 180°F to 190°F to achieve closed-loop operation, then lowered the specification in later years.)
- A certain time must have elapsed since the last engine restart (from a few seconds to 1 or 2 minutes).

During the 2000s, manufacturers began changing this strategy to achieve closed-loop operation more quickly. The required elapsed time on modern vehicles is typically 10 to 20 seconds;

heated oxygen sensors are being used to get them up to operating temperature more quickly, and PCMs are now programmed to require ECT sensors to achieve only 40°F to 50°F (some as low as 32°F or even lower on a few applications). Basically, for many cold starts (depending upon weather and also whether the vehicle is garaged), the ECT sensor has effectively been taken out of the equation. This reprogramming allows the PCM to get into closed-loop control more quickly and results in further reduced toxic emissions during most of the engine warm-up process.

DIAGNOSTIC EQUIPMENT

Scan Tools

OBD II PCMS continuously performs tests to make sure everything that affects emissions is working properly and to provide universal DTCs to help in troubleshooting.

But you still need diagnostic equipment. The most prominent example of this is the scan tool, a microprocessor-based handheld test instrument that gives you the capability of accessing the engine management data stream (see Chapter 6). You can then carefully consider this information to see if it makes sense when compared to the symptoms that caused the car to be brought in for service.

A scan tool will give you a great deal of important troubleshooting information, but many technicians do not make full use of its capabilities, using it only to pull codes. This is unfortunate because in most cases the data a scan tool provides is exactly what is essential to find the cause of the trouble. The following is a partial list of the information available on GM cars through a typical scan tool:

- DTCs, both current and historical
- oxygen sensor signal in millivolts
- rear oxygen sensor signal in millivolts
- loop status
- rich/lean flag
- power enrichment on/off
- oxygen sensor cross-counts
- injector pulse width in milliseconds
- fuel trim cell
- fuel trim index
- short-term fuel trim (STFT) and average
- long-term fuel trim (LTFT) and average
- engine RPM
- desired idle RPM
- coolant temperature
- intake air temperature
- MAP signal
- barometric pressure signal
- throttle position volts
- throttle angle as a percentage
- calculated air flow
- low-octane fuel spark modifier
- spark advance in degrees
- knock retard in degrees
- knock signal (yes/no)
- open/closed-loop indication
- converter high-temperature condition (yes/no)
- air control solenoid (port/atmosphere)
- EGR desired position as a percentage
- EGR actual position as a percentage
- EGR pintle position in volts
- EGR duty-cycle percentage
- EGR auto-zero (inactive/active)
- idle air control position
- waste gate position
- park/neutral position
- PRNDL switch position
- commanded gear
- brake switch on/off
- MPH/KPH
- TCC/shift light on/off
- fourth gear switch on/off
- A/C request (yes/no)
- A/C clutch on/off
- battery voltage
- fuel pump volts
- intake tune valve on/off
- purge duty cycle percentage
- purge learn memory
- PROM ID
- time from start

This kind of information will help you cure the majority of driveability/emissions problems, regardless of whether they have set a code.

Another extremely important feature is that you can read all that important data simply by plugging the scan tool into the DLC and pushing buttons or scrolling through menus. In fact, most technicians who have taken the time to learn the simple basics of scan tool operation typically use it before they even consider hooking up any other type of diagnostic equipment. It is usually the first tool deployed in driveability/emissions diagnosis.

A scan tool may also allow you to activate components normally controlled by the PCM. In Chrysler's actuator test mode (ATM), for instance, the company's DRB-III (Diagnostic Readout Box, third generation) scan tool, or aftermarket equivalent scan tool, can actuate the following:

- all ignition coils individually
- all fuel injectors individually
- idle air control motor
- radiator fan control module
- A/C clutch relay
- auto shutdown relay
- duty-cycle EVAP purge solenoid
- generator field
- torque converter clutch (TCC) solenoid
- EGR solenoid
- fuel system test
- speed control vacuum solenoid
- speed control vent solenoid
- fuel pump relay
- all other solenoids/relays
- set engine RPM in 100 or 125 RPM increments from 800 to 2000

This test procedure can be very helpful because if a component functions as it is supposed to (you may hear or feel a click or see fuel spray), you can be fairly sure its wiring and driver circuit are okay.

Certain computer system functions are only accessible using the manufacturer's own scan tools—for example, bidirectional control of the braking system and the ability to force transmission shifts. Forcing abnormal system operation can cause system damage or even uncontrolled braking. The manufacturers have taken the position that the ability to control these functions should be left to dealership personnel.

Of course, scan tools designed for use on 1996 and newer cars also fulfill the requirements for OBD II tests. Besides general engine data, there is a category called *specific engine data.* GM's specific engine data, for example, includes:

- information specific to EGR system diagnosis
- information specific to EVAP system diagnosis
- information specific to the diagnosis of misfire
- information specific to the HO_2S 1 and HO_2S 2 sensors

Another category is *DTC data.* This includes freeze frame data, which is information gathered at the moment a DTC is set. From this, the technician can re-create the conditions that were present at the time the code was set. Also in DTC data are failure records, which contain the information present at the time a diagnostic test was failed; this data is not necessarily associated with MIL activity.

An especially powerful troubleshooting combination is the use of a scan tool in combination with a four-gas (HC, CO, O_2, and CO_2) or five-gas (add NO_x) infrared exhaust analyzer. This allows you to compare sensor signal or computer command information with actual tailpipe emissions to see if the logical result of your readings is indeed occurring.

Pinpoint Testing

No matter how well your scan tool works and how well you understand what it is telling you, a scan tool still only identifies specific problem *areas* and does not perform pinpoint tests. The two primary pinpoint test tools are DVOMs and DSOs (covered in Chapter 6). Either of these tools can be used to identify the exact cause of a symptom, be it a circuit problem or a component.

Perhaps the glitch occurs so quickly that a DVOM's display cannot show it, or you need to measure a time interval, such as the response time of an oxygen sensor. In these cases you may find the lab scope or DSO to be very helpful. Because of the way in which a lab scope acquires and displays signals, it can add immense troubleshooting power to your ability to diagnose an OBD II system. Because the potential sampling rate can be extremely high (depending on the time-per-division adjustment), every important detail of a signal or event can be displayed. Think of your lab scope as a high-speed visual voltmeter with which you can test anything that you can test with a DVOM. Nothing about OBD II changes the way in which you use a lab scope, and no updated cartridges are needed for this piece of equipment. Simply use your scan tool with the power of an OBD II PCM to narrow down the problem area, and then use your DVOM and DSO for the required pinpoint testing.

SUMMARY

In this chapter we have covered the "why" and the "how" of OBD II and have shown how the OBD II program has made diagnosis much more standardized for all vehicles. This standardization has assisted today's technicians in diagnosing vehicle problems more accurately, resulting in cleaner exhaust emissions and, ultimately, cleaner air.

▲ DIAGNOSTIC EXERCISE

1. An OBD II–equipped car has a burned valve. How will the system prevent fuel from passing through the cylinder and overheating the catalytic converter?
2. What advantage comes from reading the sensors' information and testing actuators through the OBD II connector rather than directly testing them on the car with the harness disconnected?

Review Questions

1. What advantage for the independent technician is provided by OBD II?
   A. It is designed to standardize diagnosis of vehicle emissions and driveability-related problems.
   B. It is designed to force all vehicle manufacturers to use exactly the same engine computer system, including sensors and actuators.
   C. It is designed to force vehicle manufacturers to use new, totally redesigned computer systems in place of the systems that were already in use.
   D. It is designed to standardize the wiring colors used by all manufacturers.
2. The standardized self-diagnostic computer systems known as OBD II were required on all cars as of what year?
   A. 1986
   B. 1991
   C. 1996
   D. 2000
3. OBD II standardizes all *except* which of the following?
   A. DLC shape, size, and location
   B. Terms and acronyms
   C. Wiring colors used throughout the vehicle
   D. DTC format
4. Technician A says that OBD II represents a revolutionary change in the way that computers control engines to maximize performance, economy, and emissions. Technician B says that the snapshot feature of the OBD II self-diagnostics program is the ability of the PCM to record relevant engine parameters when a fault is recorded. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
5. How does an OBD II PCM detect cylinder misfire?
   A. Through input from the vehicle speed sensor (VSS)

   B. Through input from a high data rate crankshaft position (CKP) sensor
   C. Through input from the knock sensor
   D. Through input from the manifold absolute pressure (MAP) sensor
6. If an OBD II PCM detects a type A misfire, it will default to open-loop operation and shut down the fuel injectors on the misfiring cylinders to protect which of the following?
   A. Engine block
   B. Ignition system
   C. Oxygen sensors
   D. Catalytic converter
7. What is the purpose for placing a heated oxygen sensor after the catalytic converter?
   A. To help the PCM control the air/fuel mixture while in open loop
   B. To help the PCM control the air/fuel mixture while in closed loop
   C. To allow the PCM to monitor the catalytic converter's ability to store and use oxygen
   D. To allow the PCM to test the oxygen sensor placed before the catalytic converter
8. Technician A says that the reason OBD II was adopted was to make diagnosis of a driveability complaint more uniform. Technician B says that the reason that OBD II was adopted was due to concern about automotive emissions and air pollution. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
9. To evaluate the EGR system, Chrysler's OBD II PCM selects an operating mode in which the EGR is held open. Then it closes the EGR valve and maintains the current pulse-width command to the fuel injectors while monitoring which of the following?
   A. MAP sensor
   B. Oxygen sensor
   C. Crankshaft RPM
   D. Vehicle speed sensor
10. Technician A says that an OBD II DTC that begins with P1 is for the powertrain and is specific to the vehicle manufacturer. Technician B says that an OBD II DTC that begins with P0 is for the powertrain and is an SAE standardized code. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
11. Technician A says that an OBD II drive cycle is a specific set of driving conditions designed to allow the PCM to perform all of the required monitoring sequences. Technician B says that the PCM performs all of the tests required by OBD II instantaneously as soon as the engine is started. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
12. A hexadecimal value can be identified by placing what symbol in front of the hex code?
    A. #
    B. $
    C. *
    D. %
13. The hexadecimal value "E5C7" is equal to which of the following binary numbers?
    A. 1110010111000111
    B. 1111010111100110
    C. 1110011111101010
    D. 0111011011100101
14. How many generic scan tool requests (test modes) are reserved under OBD II standards?
    A. 7, of which 5 are defined today
    B. 12, of which 7 are defined today
    C. 15, of which 9 are defined today
    D. 21, of which 15 are defined today
15. Technician A says that, in most cases, the first time that an emissions-related fault is detected, a "pending," "maturing," or "failed last time" code will be set. Technician B says that, in most cases, the second time an emissions-related fault is detected, the PCM

will set a DTC in memory and turn on the MIL. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

16. Technician A says that if a misfire of sufficient severity to cause the catalytic converter to reach 1800°F is detected, the PCM will flash the MIL. Technician B says that the PCM will not turn on the MIL until the third detection of a type A misfire. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
17. On some enhanced OBD II systems, how does the PCM test the fuel tank for leaks?
    A. By applying manifold vacuum to the fuel tank
    B. By using a pressure sensor to monitor the pressure/vacuum within the fuel tank
    C. By pressurizing the fuel tank with nitrogen, then monitoring for the presence of nitrogen in the air around the fuel tank
    D. Both A and B
18. What input values may be monitored by an OBD II PCM to determine whether the secondary air injection system is operating properly?
    A. The manifold absolute pressure (MAP) sensor
    B. The mass airflow (MAF) sensor
    C. The oxygen (O_2) sensors
    D. The CKP sensor
19. Technician A says that an OBD II PCM will turn on the MIL if both the short-term fuel trims (STFTs) and the long-term fuel trims (LTFTs) reach predetermined limits in two consecutive drive cycles. Technician B says that virtually all vehicles will be exempt from the OBD II standards that require the PCM to monitor for chlorofluorocarbons. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
20. Technician A says that a scan tool can give the technician a large amount of information when connected to an OBD II DLC. Technician B says that a DVOM or lab scope (DSO) may be needed to pinpoint test a problem on an OBD II system after a scan tool has been used to narrow down the area of the problem. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

Chapter 9

Multiplexing Concepts

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Recognize why multiplexing is reducing hard wiring on many electronic systems, both automotive and non-automotive.
- ☐ Describe the differences between the two types of circuitry commonly used to form a data bus.
- ☐ Understand the methods used to minimize the effects of an induced voltage on the data bus.
- ☐ Describe the electrical configurations of a data bus and their advantage and disadvantages.
- ☐ Describe how a control module communicates on an SAE-standardized J1850 data bus.
- ☐ Understand the abilities of a scan tool and a lab scope when using them to perform any diagnosis of computers that communicate on a data bus or to diagnose problems with the data bus itself.

KEY TERMS

Active Voltage
Arbitration
Asynchronous
Binary Code
Data Bus Network
Demultiplexor (DEMUX)
Hard Wiring
Kilobyte
Loop Configuration
Master
Megabyte
Multiplexing (MUX)
Multiplexor
Node
Passive Voltage
Pulse-Width Modulated (PWM)
Serial Data
Slave
Star Configuration
Variable Pulse Width (VPW)

For many years, when an automotive manufacturer decided to add another feature, it involved simply adding more wiring to complete the needed circuits. Even with computer-controlled systems, adding more features meant adding more computers, more actuators, and more wiring to connect them. Many of these computers required inputs from the same sensors or from multiple similar sensors. For example, many older vehicles had three coolant temperature sensors or switches: one to control the operation of the electric cooling fan, one to control the coolant temperature gauge or warning light, and one that acted as an input to the PCM. What would be the results if we could provide sensor information to just one computer and then have that computer communicate what it knew about these sensors to the other computers that needed the same information? This concept is known as **multiplexing (MUX).**

MULTIPLEXING OVERVIEW

Hard Wiring

Before the advent of multiplexing, each sensor was wired to each of the computers that needed that sensor's input with **hard wiring.** Hard wiring is any copper wire that performs only one function 100 percent of the time. This includes simple electrical circuits that operate electrical devices, input circuits from sensors to a computer, output circuits through which a computer controls an actuator, and circuits that provide power and ground to a computer.

Elimination of Hard Wiring

A multiplexing circuit is a circuit that can be used to communicate more than one message across it, thereby eliminating the need for multiple wires to perform the same work. By this simple definition, Ford Motor Company has been using multiplexing in its speed control systems since the mid-1960s. *The speed control command switches* (SCCS), mounted in the steering wheel, consisted of either four or five switches. As the driver operated each switch, various voltage or ground signals, modified by resistances, were communicated to the transducer or control module over a single circuit. This was important because any additional wires would have created the need for additional slip rings in the steering column and steering wheel assembly (prior to the use of clock springs that are used with air bags).

Of course, today's modern multiplexing systems, as they are used with digital computers, do not simply use resistances to modify the message but instead communicate with digitized code, known as **binary code** or **serial data.** Circuits over which serial data is communicated are known as a **data bus network** (Figure 9–1). Any computer that communicates on a data bus is called a **node.** If a node contains a **multiplexor (MUX)** IC chip, it has the ability to send messages on the data bus. If a node contains a **demultiplexor (DEMUX)** IC chip, it has the ability to receive and decipher messages on the data bus. Most major nodes contain both a multiplexor and a demultiplexor and thus have the ability to both send and receive messages on the bus. The data bus circuits do not fall into the category of hard wiring because they are not limited to one job 100 percent of the time but instead may communicate one message in one instant and a totally different message in the next.

Some of the computers that may constitute nodes on the data bus include the PCM, the body control module (BCM), the instrument panel controller (IPC), the electronic brake control module (EBCM) or antilock brake control module (ABCM), the automatic transfer case module (ATCM), and several other computers including trip computers, message centers, antitheft warning systems computers, antitheft disabling system computers, electronic suspension system computers, and the computer that controls the heating, ventilation, and air-conditioning system. Instead of running hard wiring from each of the sensors to each of the computers, sensor information is shared on the bus. Additionally, the data link connector (DLC) will typically be connected to one or more of the data busses on the vehicle. This allows a scan tool to become a node on these busses for diagnostic purposes.

Typically, one computer (often the BCM), known as the **master,** controls the data bus. The other computers that are dependent on the data bus are known as **slave** computers. Some manufacturers prefer to refer to these nodes as *primary* and *secondary* nodes.

Advantages of Multiplexing

Ultimately, multiplexing eliminates dedicated hard wiring and wiring connectors, thereby reducing vehicle weight while improving dependability. Multiplexing also reduces manufacturing costs and increases the computers' diagnostic abilities. It also allows the addition of many more features while potentially using fewer computers to perform them. In fact, on a fully multiplexed vehicle, the manufacturer could conceivably add

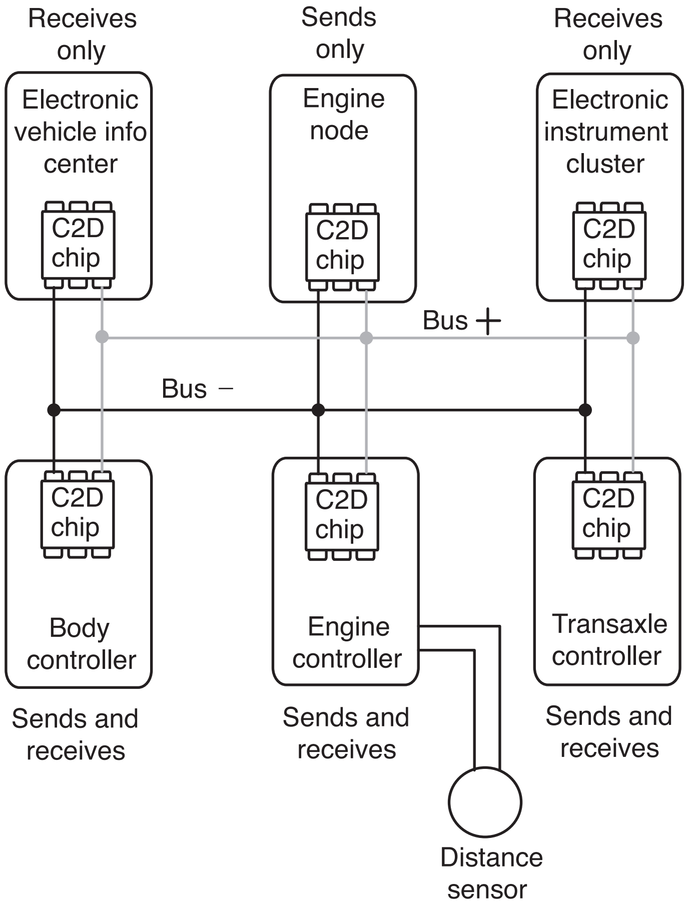


Figure 9–1 Chrysler data bus network schematic.

a feature to an existing vehicle by simply providing a software update over the multiplex network to a particular control module. This would install the added feature without having to add additional control modules or wiring.

The Popularity of Multiplexing

Multiplexing is employed in many of today's technologically advanced components and systems, both automotive and non-automotive. Telephone systems employ multiplexing extensively. Your personal computer uses the same principles in communicating to and from the monitor, keyboard, printer, scanner, and other computers on a network. For years, popular video cameras have been equipped with a multiplex port that can be linked with a patch cable to a video editor. The patch cable provides a two-way data bus for communication purposes between the components that it connects. Home security systems use a data bus to connect the keypads to the primary controller, which typically has the ability to communicate serial data over the phone lines to a central monitoring station. And modern clothes washing machines may even communicate information to the paired dryer about the type of clothing that will be transferred from the washer to the dryer, thus becoming the dryer's next load. As you can see, learning about how automotive multiplexing systems work will also enhance your understanding of how many modern non-automotive systems work.

MULTIPLEX SYSTEM DESIGNS

Multiplex Communication

In certain instances, automotive multiplexing circuits may communicate combinations of on and off signals that are sent over fiber-optic material (similar to the way some CD/DVD players are connected to an audio receiver/amplifier), but most automotive applications communicate combinations of voltage on and off signals (or high-voltage and low-voltage signals) that are sent over copper wire. These signals are referred to as "ones" and "zeros." Each one or zero is called a bit of information and, when all are strung together, they eventually form a complete word or byte. (See Chapter 2 for a more detailed explanation of bits and bytes.) "Bit" is short for "binary digit" and "byte" is short for "binary term." The prefix "kilo" (normally used to indicate a multiplier value of 1000), when used with "byte" to form **kilobyte,** indicates a value of 1024 bytes of information. (1024 is equal to the number of *combinations* of zeros and ones available when a base-2 numbering system is carried out to 10 places. It is also the base-10 value of the eleventh column in a base-2 numbering system.) Similarly, a **megabyte** indicates a value of 1,048,576 (1024^2) bytes of information. And a gigabyte indicates a value of 1,073,741,824 (1024^3), while a terabyte indicates a value of 1,099,511,627,776 (1024^4).

Two-Wire versus Single-Wire Data Busses

Many multiplexed circuits use two wires to complete the data bus circuitry between all nodes, one for bus positive and the other for bus negative. This is also commonly known as a dual-wire (DW) bus. The negative wire connected between all nodes on the bus makes for a cleaner signal on the bus positive wire (as is also done with many ignition systems between the ignition module and the PCM). The two wires are then twisted together to minimize the effects of an induced voltage (Figure 9–2). This data bus is known as a *twisted pair.* Comparison of the wires to each other, not to chassis ground, is used to decipher the binary code on these wires. Because the wires are twisted together, a voltage that might be induced on either wire by a nearby circuit is likely to be induced equally on both wires, and thus will not affect the voltage difference between the two wires. Therefore, the binary code is unaffected.

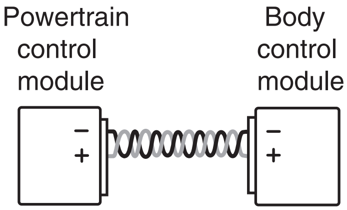


Figure 9–2 A twisted pair of wires forms the data bus that connects between nodes.

To reduce wiring complexity even further, many data busses use a single-wire (SW) bus to connect all of the nodes together (Figure 9–3).

Pulse Width Modulated versus Variable Pulse Width

Typically, most DW busses and some SW busses use binary code that has a fixed pulse width. That is, all bits (zeros and ones) will be the same length (Figure 9–4). The serial data on these data busses is said to be **pulse-width modulated (PWM).** With this type of binary code, a binary one is usually a high-voltage pulse (which

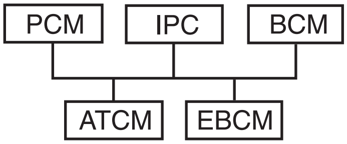


Figure 9–3 A single-wire data bus.

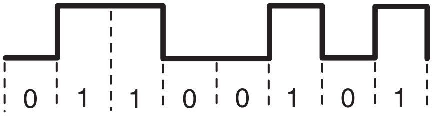


Figure 9–4 Pulse-width modulated serial data is formed from binary code in which all bits of information are equal in length.

may be ½ V, 5 V, or 7 to 8 V) and a binary zero is a low-voltage pulse (zero volts or even a negative voltage; when the zero is a negative voltage, technically, the binary code is in the form of an AC digital voltage).

However, many SW busses use a **variable pulse width (VPW)** design. On these busses, the binary ones and zeros are not only a function of the voltage value but are also a function of bit length. With VPW data, a binary one may be represented as a short high-voltage pulse, but it may also be represented as a long low-voltage pulse. Conversely, a binary zero may be represented as a short low-voltage pulse or a long high-voltage pulse. This allows the voltage to switch between high and low with each bit of information (Figure 9–5). On many SW busses that use VPW data, the digital bits are slightly trapezoidal in shape (Figure 9–6). If you were to look at this serial data with a lab scope, you would see that the waveform is not truly vertical at the bits' edges, but, rather, the edges are slanted. This allows the nodes on the data bus to distinguish between serial data and an induced voltage from a nearby circuit, which would tend to be more vertical at the edges.

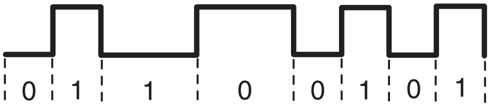


Figure 9–5 Variable pulse-width serial data is formed from binary code in which bits of information are of different lengths.

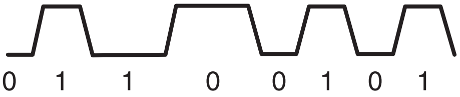


Figure 9–6 VPW serial data on a single-wire data bus has a slightly trapezoidal shape to its waveform.

Data Bus Configuration

Early automotive data busses were wired from one node to the next in a series circuit or **loop configuration** (Figure 9–7). Unfortunately, if one node on the bus were to lose power or ground, it could interrupt bus communication, affecting all nodes on the bus. Newer configurations tend to wire the nodes to the data bus in a parallel fashion, known as a **star configuration** (Figure 9–8). While the data bus itself could still be shorted to power or ground, if a node on the bus were to lose power or ground, the communication among other nodes on the bus would likely be unaffected. Another advantage is that the system can be designed to allow scan tool connectivity to only one node or to a selected few. A bus bar may be used to complete the bus connection between nodes (Figure 9–9). If the bus bar is removed, all nodes are isolated from one

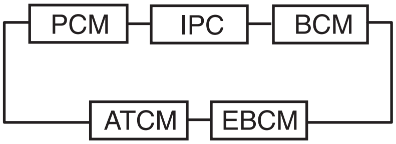


Figure 9–7 Loop design data bus, with all nodes wired in series to one another.

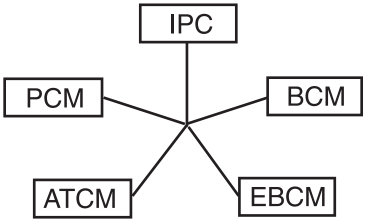


Figure 9–8 Star design data bus, with all nodes wired in parallel to one another.

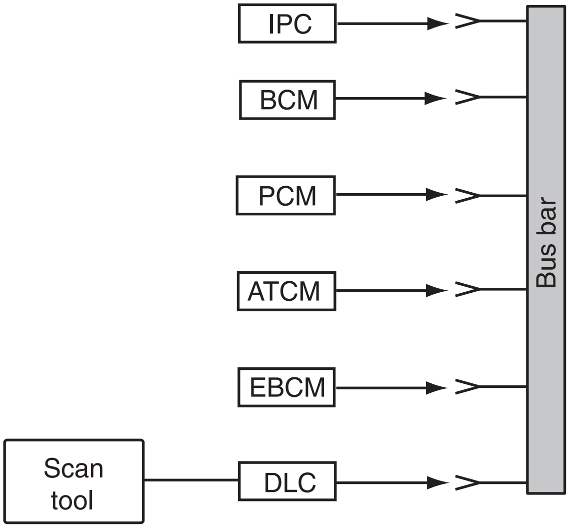


Figure 9–9 Star design data bus with a bus bar present for diagnostic purposes.

another. A jumper wire may then be used to connect the bus circuit from the DLC to a selected bus circuit. In this method, scan tool diagnosis can be done with the scan tool connected to one or more selected nodes.

MULTIPLEXING PROTOCOLS

Protocols: Language of the Computer

A *protocol* is simply the language in which computers communicate with one another over a data bus. In other words, it is a standardized binary code. Different protocols may vary in baud rate and may also vary as to whether they are a PWM or VPW design. Protocols may also differ according to what voltage level equals a one or a zero. And, while nodes on some older applications communicated to a scan tool continuously with a nonending, steady stream of information, nodes on modern networks communicate intermittently and only as needed. The latter is known as an **asynchronous** protocol.

Protocol Classes

Society of Automotive Engineers (SAE) has defined four different classes of protocols according to their speed of communication or baud rate. A class A protocol is a low-speed protocol that has a baud rate of less than 10,000 bits per second (10 K b/s), as was used with older systems. A class B protocol is a medium-speed protocol that has a baud rate of 10,000 bits per second (10 K b/s) to 125,000 bits per second (125 K b/s); this is commonly used on modern systems to control most systems except real-time control systems. A class C protocol is a high-speed protocol that has a baud rate of 125,000 bits per second (125 K b/s) to 1,000,000 bits per second (1 M b/s); this is used for some real-time controls, such as “drive-by-wire” and “brake-by-wire” systems. Finally, a class D protocol is an ultra-high-speed protocol that is also used for some real-time control systems and has a baud rate in excess of 1,000,000 bits per second (1 M b/s).

Common Protocols

Early protocols used on automotive applications include GM’s UART (universal asynchronous receiver-transmitter) protocol and Chrysler’s C2D (Chrysler Collision Detection) protocol. These are class A protocols that handle PWM data. Chrysler’s term *collision detection* refers to the process of preventing two or more messages from colliding on the data bus.

While many protocols have been developed and used by the different manufacturers over time, in the interest of maintaining standardized communications with aftermarket scan tools, OBD II standards initially defined four protocols that could be used on U.S. automobiles. The accepted protocols are defined by the SAE and the ISO (International Standards Organization). These standards apply to the protocols that are to be used between the nodes on the bus and an OBD II–standardized scan tool (as per the SAE J1978 standard) for diagnostic purposes. For example, Chrysler, Ford, and General Motors engineers, working closely

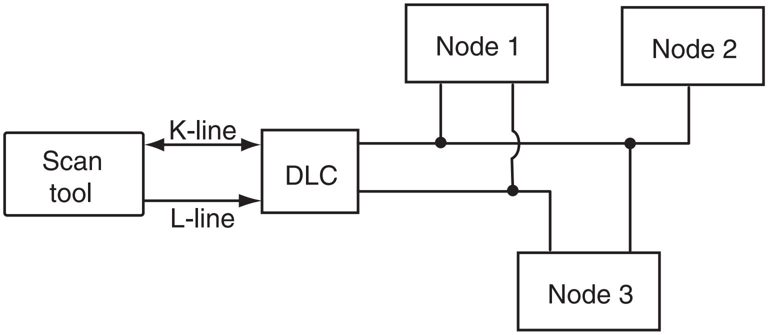


Figure 9–10 ISO 9141 data bus.

with each other to meet the OBD II regulations, developed the SAE J1850 protocol.

As these protocols are mandated under OBD II standards, the manufacturers are given a certain time frame within which to meet each standard. The four protocols that were initially accepted under OBD II standards were phased in by most manufacturers between 1996 and 2000, as follows:

1. *SAE J1850 VPW protocol:* This protocol is a class B protocol at 10.4 K b/s and is used as an SW bus by General Motors as its class 2 network and by Chrysler as its programmable communication interface (PCI) network. This protocol will no longer be allowed after the 2007 model year.
2. *SAE J1850 PWM protocol:* This protocol is a class B protocol at 41.6 K b/s and is used as a DW, twisted-pair bus by Ford as its standard corporate protocol (SCP) and audio corporate protocol (ACP) networks. This protocol also will no longer be allowed after the 2007 model year.
3. *ISO 9141/ISO 9141-2:* This protocol is used primarily on European vehicles. However, it is also used in some domestic applications. In fact, CARB initially adopted the ISO 9141 protocol for all vehicles sold in California with feedback fuel management systems. The ISO 9141 protocol uses an SW bus called the *K-line.* The K-line allows for bidirectional communication between a scan tool and the nodes on the bus. An optional *L-line* is sometimes used to allow one-way communication from the scan tool to the nodes on the bus (Figure 9–10). The original ISO 9141 protocol was enhanced in 1994 to meet CARB requirements and became the ISO 9141-2 protocol. This protocol will no longer be allowed after the 2006 model year.
4. *ISO 14230-4,* also known as *KWP 2000* (Keyword Protocol 2000): This protocol is a newer version of the ISO 9141-2 protocol and was introduced in 2000. This protocol will no longer be allowed after the 2007 model year.

A fifth protocol, known as the ISO 15765-4 Controller Area Network (CAN) protocol, has been added to the list of OBD II protocols. The CAN protocol was originally developed by Robert Bosch in the 1980s and has, in the past, been used on some European vehicles, such as Mercedes-Benz and Volvo, to provide communication between the nodes on a bus. A particular node, the PCM for example, would then serve as a gateway and translate CAN information into the ISO 9141 protocol for a scan tool connected to the DLC (Figure 9–11).

The CAN system has been updated as follows: *Legislated CAN,* known as the ISO 15765-4 CAN protocol, is designed to provide functionality to a generic scan tool connected to the DLC concerning emissions system diagnostics, while *OEM Enhanced CAN* conforms

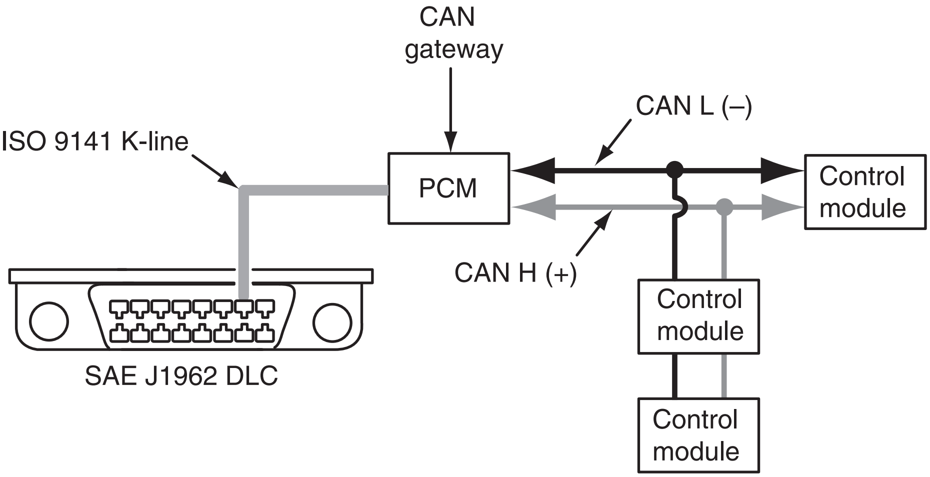


Figure 9–11 Early use of the CAN protocol on European vehicles showing the PCM as a gateway to the DLC.

to OEM proprietary specifications for providing manufacturer scan tool functionality when diagnosing powertrain, body, or chassis systems. Two versions of CAN networks are available: a SW bus with baud rates ranging from 33.3 K b/s to 83.3 K b/s and a DW bus with baud rates ranging from 125 K b/s to 500 K b/s. Manufacturers began phasing in the ISO 15765-4 CAN protocol on 2003 model-year vehicles, and full implementation has been mandated under OBD II standards by the 2008 model year, replacing all other existing protocols for diagnosing those systems that can affect the vehicle's emissions. The implementation of the CAN system from 2003 through 2008 can be found in the public files folder on the following web site: http://www.etools.org. Actually, the chart available on this Web site shows all the protocols used from 1996 through 2008. One point to note is the fact that one of the factors resulting in CAN implementation prior to the 2008 model year is the addition of real-time control systems, such as drive-by-wire.

Note: Intel has been one of the primary companies involved in the design of automotive multiplexing networks and has designed products that incorporate both J1850 and CAN functionality.

COMMUNICATION ON A J1850 VPW DATA BUS

Overview of the J1850 VPW Protocol

Because the VPW version of the SAE J1850 protocol was used on a large number of GM and Chrysler vehicles, it is presented in some detail here. However, many similarities exist between this protocol and other protocols, including the ISO 15765-4 CAN protocol. Although the ISO 15765-4 CAN protocol uses a much faster baud rate, the CAN message contains many of the same parts as an SAE J1850 VPW message (simply adding some additional segments to it) and also uses the same method of **arbitration** as the SAE J1850 VPW protocol. Therefore, the following breakdown of the SAE J1850 VPW protocol can be taken as a typical example of modern protocols used throughout the automotive industry.

Passive versus Active Bits

A **passive voltage** is a voltage that is at rest. An **active voltage** is a voltage that is actively pulled either high or low by a computer circuit. On a J1850 data bus, a passive voltage is a low

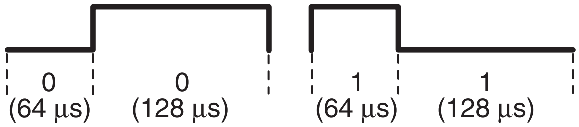


Figure 9–12 SAE J1850 VPW protocol bit length.

voltage that is close to ground (between zero volts and 3.5 V). The J1850 standard defines an active voltage as one that is pulled high (between 4.25 V and 20 V). To allow the voltage to switch with each bit of binary code, a one may be either a short active voltage pulse (a high-voltage pulse that lasts 64 μs) or a long passive voltage pulse (a low-voltage pulse that lasts 128 μs). Conversely, a zero may be either a short passive voltage pulse (a low-voltage pulse that lasts 64 μs) or a long active voltage pulse (a high-voltage pulse that lasts 128 μs) (Figure 9–12).

The J1850 Message

The J1850 message begins with a *start-of-frame* (SOF) signal, an active voltage pulse that lasts for 200 μs (Figure 9–13). This is followed immediately by the next portion of the message, called the *header.* The header's first byte designates message priority, whether the header is 1 or 3 bytes long, whether an *in-frame response* (IFR) is required from the receiving node, an address identification that identifies both the sender and the intended receiver, and the intended message type.

The next portion of the message is the data field, which contains the "meat" of the message and may be up to 11 bits in length. This is immediately followed by a *cyclic redundancy check* (CRC) byte. The CRC and the data field together are considered one "word" and do not exceed 12 bits in length. For example, if the data field is 11 bits, the CRC is 1 bit. If the data field is less than 11 bits, the CRC can be more than 1 bit as long as the total does not exceed 12 bits when added to the data field. The purpose of the CRC bit is to guard against message error. The receiving nodes add the CRC value to the value of the data field to calculate whether message errors have occurred.

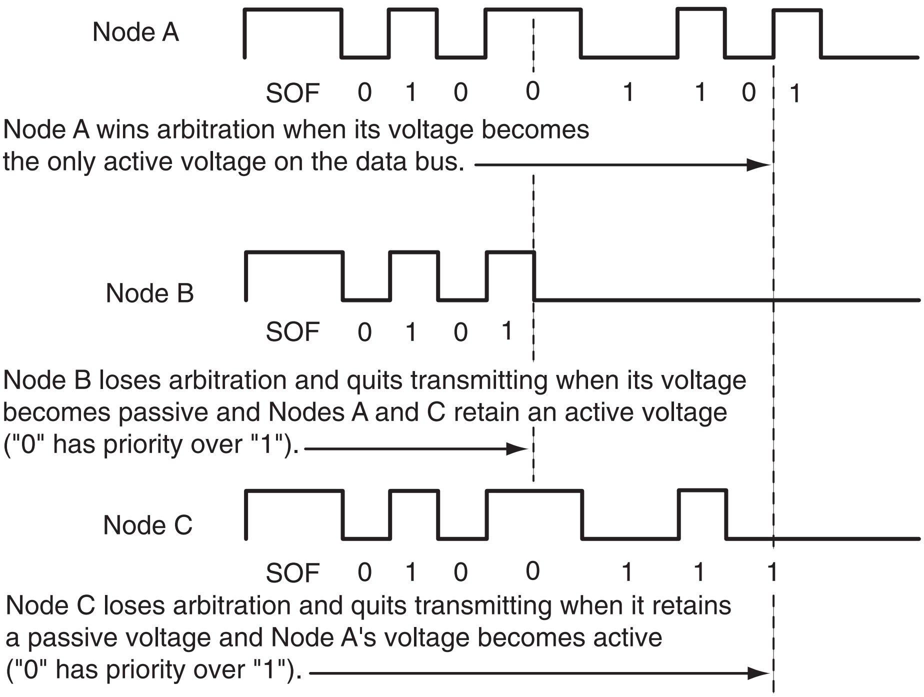
SOF	Header field	Data field	CRC	EOD	IFR (if required)

Figure 9–13 The SAE J1850 VPW bus message.

The CRC is then followed by an *end-of-data* (EOD) pulse. This is a passive voltage that lasts 200 μs. If requested in the header field, the receiving node must issue an IFR within the next 80 μs. This allows the transmitting node to be certain that the intended receiver received the message. Think of it as a handshake between the transmitting node and the receiving node, similar in concept to the "handshake" that occurs between fax machines when the tones from the sending unit are responded to by a tone from the receiving unit.

Arbitration

A node on the data bus will "listen" to make sure that the bus is "quiet" before it begins transmitting data on the bus. But because the J1850 protocol supports peer-to-peer networking that allows equal access to all nodes on the data bus, occasionally, more than one node may begin to transmit data simultaneously. Arbitration is the process of determining which node can continue to transmit data on the bus when two or more nodes begin transmitting data at the same time. The SAE J1850 protocol uses bit-by-bit arbitration to compare active and passive bits on the bus. When a node that is transmitting a passive, low-voltage pulse sees the data bus circuit voltage pulled actively high by another node on the bus, it quits transmitting. That is, when a node transmits a passive voltage and sees another node's active voltage, it is said to lose arbitration. The nodes with the active voltage continue to arbitrate until only one node is left transmitting data. In reality, a zero is the dominant bit and always wins the arbitration when compared with a one bit. Therefore, this design is such that the node that initially transmits the most zeros wins arbitration and can continue to transmit data on the bus (Figure 9–14). The nodes that lost arbitration for the current message can try transmitting again after the winning message is complete.



Node A wins arbitration when its voltage becomes the only active voltage on the data bus.

Node B loses arbitration and quits transmitting when its voltage becomes passive and Nodes A and C retain an active voltage ("0" has priority over "1").

Node C loses arbitration and quits transmitting when it retains a passive voltage and Node A's voltage becomes active ("0" has priority over "1").

An active voltage has priority over a passive voltage. As a result, a "0" has priority over a "1" due to the fact that a "0" either stays active longer or results in an earlier switch to an active voltage.

Figure 9–14 SAE J1850 VPW bus arbitration.

COMMUNICATION ON A CAN DATA BUS

Overview of the CAN Protocol

The CAN protocol has several similarities with the J1850 VPW protocol, but there are also some differences. The CAN protocol does not use a message that defines the intended receiving nodes by addresses, but, rather, uses a message-oriented protocol. This allows all nodes on the CAN bus to simply accept or deny a broadcast message according to its content.

Recessive versus Dominant Bits

Bosch refers to a passive bit as *recessive* and to an active bit as *dominant.* However, the recessive voltage is actually a bias voltage that is supplied by one of the nodes, thus allowing the natural state of the bus to have a high voltage present when none of the nodes are attempting to communicate. A dominant value is created when one of the nodes pulls the voltage low by grounding out the bus momentarily. During active communication, the recessive voltage (high value) equates to a binary one and the dominant voltage (low value) equates to a binary zero.

The CAN Message

A base frame format (standard format) is used with the CAN 2.0 A specification (Figure 9–15). The first part of this message is the SOF, during which the bus voltage is pulled low to the dominant value (unlike the J1850 VPW bus, which at

SOF	Identifier (A)	RTR	IDE	r(0)	DLC	Data Bytes	CRC	CRC Delimiter	ACK	ACK Delimiter	EOF
1 bit	*11 bits*	*1 bit*	*1 bit*	*1 bit*	*4 bits*	*Up to 8 bytes*	*15 bits*	*1 bit*	*1 bit*	*1 bit*	*7 bits*

Figure 9–15 The CAN 2.0 A bus message.

this point pulls the voltage from low to high). The SOF is followed by an 11-bit *identifier* that is used for arbitration.

Next is the *remote transmission request,* or RTR, which is a single dominant bit (0), followed by an *identifier extension,* or IDE, which is also a single dominant bit (0). A single *reserve bit,* or r(0), comes next. This is then followed by the meat of the binary message, beginning with a *data length code,* or DLC, which consists of 4 bits and indicates the number of data bytes that are to immediately follow (up to 8 bytes of data may be transmitted).

Finally, a 15-bit CRC follows, which is used to check for message corruption. This is followed by a single recessive (1) bit known as the *CRC delimiter.* An *acknowledgement,* or ACK, field follows during which the transmitting node will allow a recessive (1) bit. Any receiving node can respond by pulling this value low to the dominant value (0) as an acknowledgment to the transmitting node that the message was received intact. Once the receiving node releases the bus from ground, the voltage returns to the recessive value, which is now referred to as the *ACK delimiter.* The ACK field equates to the IFR in the J1850 VPW protocol. The final part of the message is the EOD byte, which consists of seven recessive (1) bits in a row.

An *extended frame format,* known as the CAN 2.0 B specification, is also used. The primary difference is that the base frame format (CAN 2.0 A) has an identifier of 11 bits, while the extended frame format (CAN 2.0 B) follows this with a second identifier of 18 bits; the two identifiers, when added together, contain a total of 29 bits.

Arbitration

When two or more nodes begin to transmit a data message at the same instant in time, a dominant (0) bit in the identifier wins arbitration over a recessive (1) bit. Therefore, the lowest binary value in the identifier will always win arbitration. In reality, when one of the nodes in arbitration sees the bus voltage pulled low to a dominant (0) value at a time when it is, itself, allowing a recessive voltage, it knows that another node with a higher priority message is communicating. It will then quit transmitting and will wait until it has seen a minimum of seven recessive (1) bit pulses in a row before it attempts to communicate its message again.

There is one restriction on the identifier: The first seven bits cannot all be recessive (1) bits, since this would cause other nodes on the bus to believe that no communication is currently in progress. This is also why the EOD byte *does* consist of seven recessive bits: This serves to communicate to other nodes that the bus is now idle.

MULTIPLEXING VARIATIONS

Smart Devices

A sensor or switch can be electronically equipped to transmit binary code concerning the input values it is sensing to other components on a data bus. Conversely, an actuator can also be electronically equipped to receive, translate, and react to binary code that it receives from other components on a data bus. These components are said to be electronically "smart."

For example, many of today's vehicles have driver control switches mounted on the steering wheel assembly (either front, side, or back) that are used to control the heating, ventilation, and air-conditioning system, as well as the sound system. These switches send serial data over a data bus that connects both to the climate control module and to the radio. If a command is sent to increase the radio's volume, the binary code is received and acted upon by the radio, but is ignored by the climate control module.

Another example that demonstrates the use of smart devices is an exterior lighting system in which the driver-controlled switches are smart input devices and the exterior bulbs' sockets are actually smart actuators on a data bus. If the driver uses the directional signal stalk to signal a left lane change, the switch assembly transmits a binary message on the data bus that is only recognized by the front and rear actuators on the left side of the vehicle as a request to flash their bulbs' bright filaments. Or, when the headlight switch is turned on, all exterior actuators react to the binary request to illuminate their dim filaments continuously, including even the license plate illumination. In this manner, you can control all of the bulbs at the rear of the vehicle simply by connecting all of them with a single- or dual-data bus, thus eliminating numerous hard-wired circuits. Even the deck lid solenoid can be connected to the same data bus.

Multiple Body Computers

Whereas some vehicles have utilized a body control module (BCM) since the mid-1980s to control interior and exterior lighting systems and other body functions of the vehicle, some manufacturers have recently divided this control module into multiple computers. For example, some modern Ford vehicles now have a *front electronic module,* a *rear electronic module,* and a *driver's door module.* With such a system design, input devices and actuators are only hard wired to the closest module, whether or not the particular system is under control of that module. Then the pertinent information is shared between modules on the data bus. This allows for a further reduction of hard wiring.

For example, if the driver depresses the *deck lid release* button on the driver's door, the closing of the switch completes a hard-wired circuit to the driver's door module. This module then communicates the request over the data bus to the rear electronic module, which, in turn, energizes the deck lid release solenoid through a hard-wired circuit. As a result, a hard-wired circuit does not have to be run all the way from the driver's door switch to the deck lid release solenoid. Since the request is communicated for much of this distance over a data bus and because this bus is also used for data communication concerning many other devices as well, hard wiring is reduced.

Multiplexing and Driver Control

With the continuing explosion in the use of electronics on the modern vehicle and the expansion in intra-vehicle communication networks, the driver is becoming less and less in control of the vehicle's systems. In fact, on many modern vehicles, the driver actually controls little or nothing. For example, when the driver depressed the horn switch on a 1980 vehicle, the operation of the switch actually completed the ground needed to energize the horn relay over a hard-wired circuit. But rarely is this true today. On many modern vehicles, depressing the horn switch only makes a request of a control module. Then if the module has no reason to disagree, it will complete the hard-wired circuit to energize the horn relay. Therefore, the driver does not actually control the horn relay, but only makes a request. The computer is providing the actual control.

For example, let us say that the driver attempts to operate a convertible top while moving down the road at 20 MPH. Operating the convertible top's switch simply makes a request of the appropriate control module. But this module also sees that the vehicle's transmission is not in "park" and also sees from the VSS that the vehicle is moving. In obedience to its internal program, it would refuse to comply with the driver's request.

Another advantage of this type of engineering is the ability to take full advantage of another feature that is in its early stages: vehicle-to-vehicle communication. SAE is currently working with several manufacturers in developing this technology. Once in place, the vehicle ahead of yours could hit a 4″ deep puddle of water and hydroplane. Sensing what had happened, its onboard computers would communicate the danger to your on-board computers and, even though you have your foot pressing the throttle pedal fully, your drive-by-wire system would refuse to comply with your request due to the sensed danger ahead. Such a communication system will also be used to reduce road junction accidents due to the ability of the vehicles to communicate with each other as they approach each other. In short, today's drivers only *think* that they are controlling their vehicles.

OTHER BOSCH PROTOCOLS

Overview

Bosch, a corporation that employs approximately 9000 engineers, has continued to develop other protocols designed for mobile vehicle use. Two other protocols have been developed for manufacturers' proprietary use and/or for use with systems not affecting the vehicle's emissions and are described here.

Local Interconnect Network

The first version of the Local Interconnect Network, or LIN, protocol was released in 1999 as version 1.1. The second version, version 2.1, is now being used. LIN exists, not as a protocol to replace CAN, but rather as a protocol to complement and work as a subsystem of CAN. It is a low-cost protocol that uses no arbitration, but, instead, uses a single master node that does all of the transmitting. Up to 16 dependent slave nodes only listen except for an occasional response. The dependent slave nodes may be linked to a CAN bus through the LIN bus master node. The LIN protocol is a single-wire, low-speed protocol with possible baud rate up to 20,000 bits per second (20 K b/s).

FlexRay

The FlexRay protocol is now fully developed and ready for mass production as an addition to the automobile's electronic systems. It is a high-speed protocol, transmitting data at a baud rate of up to 10,000,000 bits per second (10 M b/s). It will likely be used for real-time control systems with its initial development being aimed at brake-by-wire and steer-by-wire systems.

The FlexRay protocol uses a timed communication as its form of arbitration. That is, each node on the data bus is programmed to communicate in a timed cycle according to a "bus clock," with each communication taking only a few milliseconds. As long as each node "takes its turn" as specified by its program, more than one node should never attempt to communicate at the same time.

DIAGNOSIS OF MULTIPLEXED CIRCUITS

Scan Tools

Multiplexing allows several computers to be accessed through the DLC for diagnostic purposes. Simply connect an OBD II–standardized scan tool (SAE J1978 standard) to the DLC and then, after the VIN information has been entered, you can choose the computer you want to communicate with from the scanner's menu. Once you have selected a computer, you will be able to pull DTCs, access the computer's data stream, perform functional tests, and perform any other functions the particular computer has been programmed to allow. On some systems, the data bus may connect to the climate control head and/or the audio system control head for diagnosis of certain systems without the use of a scan tool. Follow the manufacturer's instructions as to what tests may be done by entering information on the buttons on the control head.

Lab Scopes

If a computer on the network does not seem capable of communicating with your scan tool, a DSO may be required to evaluate whether the computer is capable of transmitting the binary code that the scan tool must see. However, do not forget that common reasons for a scanner's failure to communicate are improper entry of the VIN information or the scan tool failing to power up properly (with OBD II systems, do not forget to check the fuse that provides battery voltage to terminal 16 of the DLC). Also, in certain cases, another scan tool may communicate where one scan tool has failed.

If you cannot get a scan tool to communicate on the data bus, use a lab scope to determine whether serial data is present on the bus. With an SW data bus, connect the lab scope between the bus wire and a clean, unpainted ground. With a DW data bus, be sure to connect the lab scope between the two wires (bus positive and bus negative), rather than between bus positive and chassis ground.

Once you have connected the lab scope and turned on the ignition switch, you are simply looking for the presence (or lack) of serial data. You should not expect to be able to interpret the serial data with a lab scope, as a scan tool does. In a few older systems, the scan tool must be connected to the bus while you attempt to verify the presence of data on the bus with a DSO. With most modern systems, serial data will be present at the DLC just by reason of turning on the ignition switch. Be sure to properly set the trigger characteristics of the DSO (described in Chapter 6) to reliably display the quick, intermittent serial data as it occurs. If the lab scope shows that serial data is present at the DLC but the scan tool fails to communicate, look for a terminal at the DLC that has been inadvertently damaged, resulting in a loose connection with the scan tool. When performing this type of diagnosis, a breakout box designed for use at the DLC (as described in Chapter 6) can be extremely helpful and can also help avoid further damage to the terminals of the DLC.

Also, most systems design in a wiring hub that allows the technician to separate all the nodes on the network for diagnostic purposes. GM uses a splice bar connector, as described previously in this chapter, and Chrysler tends to use the connector at the BCM as the wiring hub of the system.

SUMMARY

This chapter presented revolutionary electrical systems that had a limited introduction into the automotive world in the 1980s; by the end of the 1990s these systems were being used on most makes of vehicles to a very large extent. Such systems will continue to expand in use. These electrical systems will be part of what the technician needs to diagnose when a vehicle comes into the shop for anything from a minor problem such as an inoperative trip computer to something as major as a no-start condition. We discussed how multiplexing is used to reduce hard wiring, thereby reducing weight and increasing dependability. We also saw how multiplexing allows additional features to be added without increasing the number of control modules or wires in the vehicle. Then we looked at how the protocols have been standardized, and we saw details of two of the most popular standardized protocols currently in use—the J1850 VPW protocol and the CAN protocol. Finally, we discussed the ways both a scan tool and a lab scope aid the technician in diagnosing problems with a multiplexed network.

▲ DIAGNOSTIC EXERCISE

A technician is diagnosing a vehicle that was towed into the shop with a "cranks, but won't start" complaint. After verifying the symptom, he connects a scan tool to the DLC and turns the ignition switch on. The scan tool displays a "No communication" message. At that point, he disconnects the bus bar to isolate all the nodes on the data bus (star configuration). He then uses a jumper wire to connect just the PCM to the DLC. With the ignition switched on, the scan tool begins communicating with the PCM. What type of problem is indicated, and how can the technician isolate the problem?

Review Questions

1. Technician A says that a multiplexed circuit can be used to communicate multiple messages. Technician B says that modern multiplexed circuits transmit serial data to allow computers to communicate with each other. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. Advantages of multiplexing include all *except* which of the following?
   A. Dedicated hard wiring and vehicle weight are both reduced.
   B. All functions on the vehicle are under the control of one physical computer.
   C. Dependability is increased.
   D. Computer diagnostic ability is increased.
3. A megabyte of information is equal to which of the following?
   A. 1000 bytes of information
   B. 1024 bytes of information
   C. 1,000,000 bytes of information
   D. 1,048,576 bytes of information
4. Technician A says that some multiplexing systems use a data bus that consists of two wires that are twisted together, known as a *twisted pair.* Technician B says that some multiplexing systems use a data bus that consists of only one wire. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
5. Why are the wires twisted together on a data bus that uses two wires to communicate?
   A. To provide greater physical strength of both wires
   B. To increase the likelihood that if one wire is severed, they both would be severed (for safety purposes)
   C. Because the data bus circuitry flows high levels of current that could affect other nearby circuits if the data bus wires were not twisted together
   D. To minimize the effects of an induced voltage on the data bus
6. Technician A says that a data bus that connects the computers in a series circuit is known as a *star configuration*. Technician B says that a data bus that connects the computers in a parallel circuit is known as a *loop configuration.* Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
7. What is a standardized binary code (or computer language) known as?
   A. Protocol
   B. Node
   C. Byte
   D. Data bus
8. Technician A says that multiplexing is unique to the automotive industry and is only used on automotive applications. Technician B says that multiplexing allows features to be added to a vehicle while at the same time reducing hard wiring. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
9. How are the effects of an induced voltage minimized on many single-wire data busses?
   A. The wire is routed inside of a grounded shield.
   B. The edges of each bit of information are slightly slanted, resulting in a slightly trapezoidal waveform shape.
   C. Multiple messages are transmitted simultaneously to ensure that the other computers on the data bus understand the message.
   D. Capacitors are connected to the data bus to minimize any voltage change.
10. Technician A says that PWM serial data has a fixed pulse width with all zeros and ones being the same length. Technician B says that VPW serial data has bits of different lengths. Who is correct?
    A. Technician A only
    B. Technician B only

C. Both technicians
D. Neither technician

11. What is a computer that can communicate on a data bus known as?
    A. Protocol
    B. Node
    C. Byte
    D. Control module
12. What is the term for the process of determining which of two computers on a data bus can continue to transmit data when they begin transmitting at the same time?
    A. Arbitration
    B. Qualification
    C. Annotation
    D. Defragmentation
13. On an SAE J1850 VPW data bus, if multiple nodes on the bus attempted to transmit data simultaneously, which of the following messages would win arbitration?
    A. 00101001
    B. 00100111
    C. 00100100
    D. 00100011
14. Technician A says that the computer that controls a data bus is known as the *master.* Technician B says that a dependent computer on a data bus is known as a *slave.* Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
15. Which of the following protocols has been mandated under OBD II standards to replace all other protocols by the 2008 model year for aftermarket scan tool communication with systems that affect the vehicles emissions?
    A. ISO 9141-2
    B. ISO 15765-4 CAN
    C. SAE J1850 VPW
    D. ISO 14230-4 (KWP 2000)
16. Technician A says that most multiplexing networks may allow you to access the computers for diagnostic purposes by connecting a scan tool to the DLC. Technician B says that some multiplexing networks may allow you to access the computers for diagnostic purposes through the climate control and/or audio system control head. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
17. Technician A says that when you connect a scan tool to the DLC, it becomes a node on the network to which it is connected. Technician B says that either a scan tool or a lab scope can be used by the technician to interpret the serial data on a data bus. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
18. Which of the following conditions can keep a scan tool from communicating on a data bus when it is connected to the DLC?
    A. The scan tool is not properly powered up.
    B. The VIN is improperly entered into the scan tool.
    C. Serial data does not exist on the data bus.
    D. All of the above.
19. Which of the following is the best tool to check for the presence of serial data on a data bus?
    A. Scan tool
    B. Lab scope
    C. Test light
    D. Short finder
20. Which of the following is the best tool to retrieve information from or issue commands to computers on a data bus?
    A. Scan tool
    B. Lab scope
    C. Test light
    D. Short finder

Chapter 10

General Motors' Electronic Fuel Injection

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Define the operating modes of a GM EFI (TBI) system.
- ☐ Define the inputs associated with a GM EFI (TBI) system.
- ☐ Describe the operation of a GM EFI (TBI) fuel system.
- ☐ Describe the operation of the idle speed control system associated with a GM EFI (TBI) system.
- ☐ Describe the operation of the spark management systems associated with a GM EFI (TBI) system.
- ☐ Understand the emissions control systems associated with a GM EFI (TBI) system.

KEY TERMS

Block Learn
Calculation Packet (CALPAK)
Light-Emitting Diode (LED)
Pickup Coil
REF Pulse
Throttle Body Injection (TBI)

General Motors introduced a computer system in 1980 that was known as the *Computer Command Control system,* also called the CCC system or C3 system. (Actually, GM's original name for this system was *Computer Controlled Catalytic Converter* or C4, but they quickly changed the name to C3.) Within the realm of the C3 system, GM had three different fuel management systems: feedback carburetion, Electronic Fuel Injection (EFI, which is covered in this chapter), and Port Fuel Injection (PFI). All three C3 systems, regardless of the fuel management system used, provided similar scan tool functionality and flash code diagnostics, including a standardized 12-pin data link connector (DLC) under the instrument panel, originally known by General Motors as the *assembly line communications link (ALCL)* or *assembly line data link (ALDL).* The 12-pin DLC was used in the C3 system from 1982 through 1995 (until OBD II mandated a 16-pin DLC).

General Motors' EFI is a single-point fuel injection system. It is often called a **throttle body injection (TBI)** system. That name, however, more precisely described a major component of the system (Figure 10–1), the throttle body with its single or double fuel injector. This system was introduced by General Motors in 1982.

Two versions of the first EFI system appeared in 1982: One used a single TBI unit for four-cylinder engines and a second, higher performance version (the Crossfire system) had two separate TBI units for eight-cylinder engines.

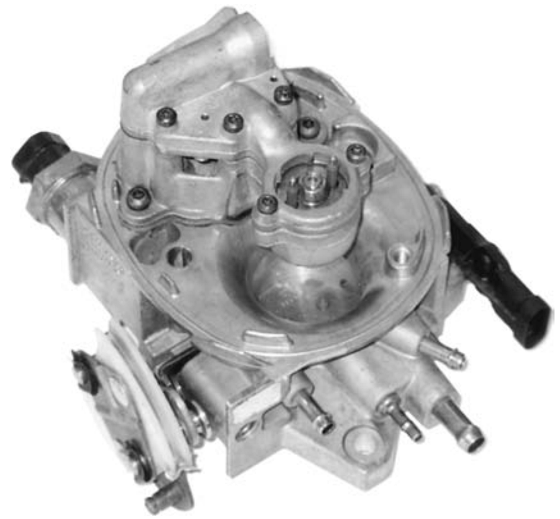


Figure 10–1 C3 TBI unit.

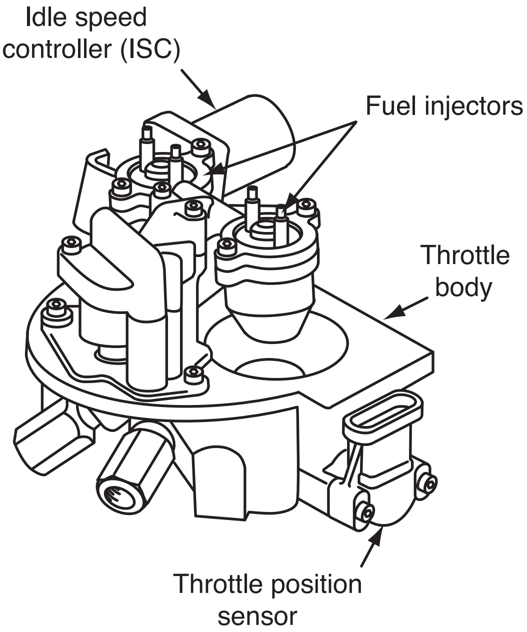


Figure 10–2 DFI TBI unit.

The latter is not to be confused with TBI systems using two fuel injectors in a single throttle body. The two-injector TBI unit was introduced on some V6 engines beginning in 1985.

Another form of the EFI system, known as digital fuel injection (DFI), was used on Cadillacs. Cadillac introduced DFI in the middle of the 1980 model year. By 1981, the system had replaced all other fuel injection systems on eight-cylinder Cadillac engines except for the diesels. The DFI system closely resembled the C3 system in many respects, including the -pin DLC under the instrument panel, but the DFI system added some additional diagnostic capabilities. Early DFI systems also used a TBI-style throttle body with two injectors, similar to the dual-injector throttle body used in C3 systems except for the idle speed control (ISC) motor (Figure 10–2).

POWERTRAIN CONTROL MODULE

The powertrain control module (PCM) (Figure 10–3) is usually located above or near the glove compartment. On some models, notably the Pontiac Fiero, it is in the console. On some Corvettes, it is in the battery compartment behind the driver's seat. Figure 10–4 shows a C3 system PCM circuit board. Its inputs and the functions it controls (its outputs) are shown in Figure 10–5.

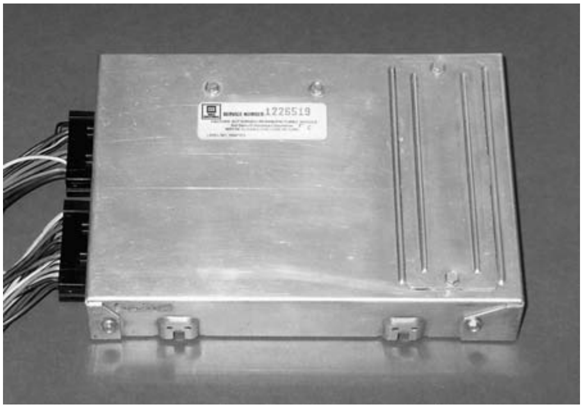


Figure 10–3 GM's Computer Command Control system PCM.

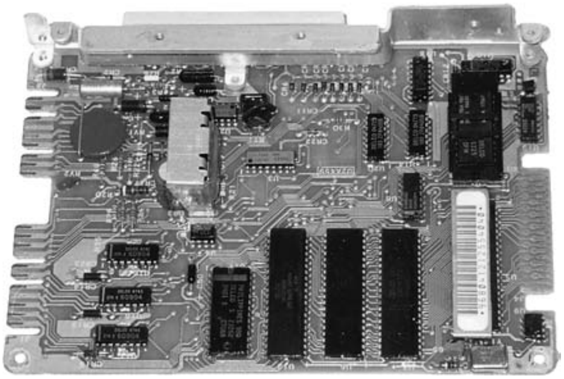


Figure 10–4 GM's C3 system PCM circuit board.

PCM for 2.5-L EFI Operates Cruise Control

The PCM for selected engines such as the 2.5-L four-cylinder engine was given more extensive and powerful internal circuitry to enable it to perform additional functions, such as control of the cruise control, in 1988.

Throttle Body Backup

The throttle body backup (TBB) is a fuel backup circuit in the PCM. It is primarily responsible for providing fuel pulses to the injector solenoid in the event of a general PCM failure, that is, a failure that prevents it from running its program. The PCM on the 2.0-L engine uses a removable **calculation packet (CALPAK)** that provides fuel backup. The CALPAK plugs into the PCM the same way the PROM does (described later in this chapter).

Fuel Trim

The EFI PCM has a learning capability called *fuel trim,* originally called **block learn.** It is designed to correct for gradually changing input values resulting from component wear that may affect air/fuel ratios. It can also compensate for driving conditions such as changing altitude, and even learns to modify output commands to complement

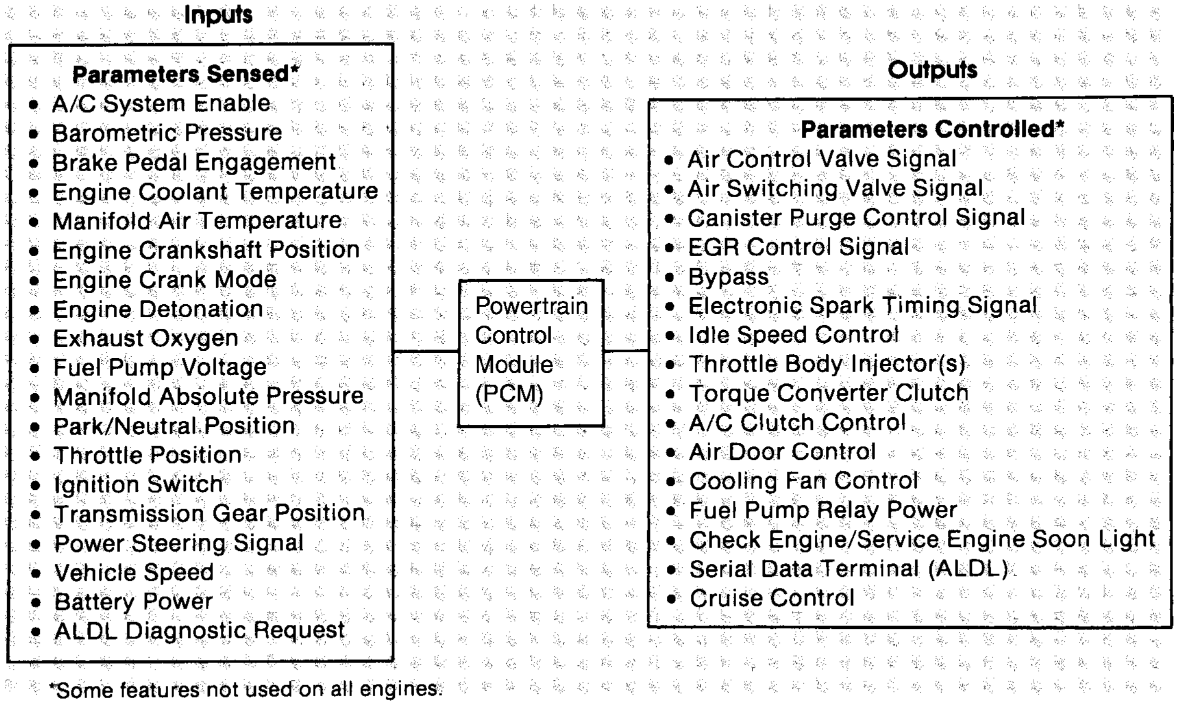

Inputs
Parameters Sensed*
• A/C System Enable
• Barometric Pressure
• Brake Pedal Engagement
• Engine Coolant Temperature
• Manifold Air Temperature
• Engine Crankshaft Position
• Engine Crank Mode
• Engine Detonation
• Exhaust Oxygen
• Fuel Pump Voltage
• Manifold Absolute Pressure
• Park/Neutral Position
• Throttle Position
• Ignition Switch
• Transmission Gear Position
• Power Steering Signal
• Vehicle Speed
• Battery Power
• ALDL Diagnostic Request
Powertrain Control Module (PCM)
Outputs
Parameters Controlled*
• Air Control Valve Signal
• Air Switching Valve Signal
• Canister Purge Control Signal
• EGR Control Signal
• Bypass
• Electronic Spark Timing Signal
• Idle Speed Control
• Throttle Body Injector(s)
• Torque Converter Clutch
• A/C Clutch Control
• Air Door Control
• Cooling Fan Control
• Fuel Pump Relay Power
• Check Engine/Service Engine Soon Light
• Serial Data Terminal (ALDL)
• Cruise Control
*Some features not used on all engines.

Figure 10–5 EFI system overview.

a particular driver's driving habits. For an in-depth discussion of fuel trim, see Chapters 4 and 11.

Keep-Alive Memory

The PCM has a keep-alive memory (KAM) like that discussed in earlier chapters. As long as it remains connected to a source of electrical power (the battery), it will retain the information it has accumulated in previous driving intervals. The amount of power required to maintain this stored information is very small, much less than the battery drain caused by internal forces in the battery itself.

OPERATING MODES

The EFI system features the typical closed-loop and open-loop modes. During open loop, the PCM is programmed to provide an air/fuel ratio most suited to driveability, as well as economy and emissions concerns. Of course, as with all computerized engine control systems, emissions concerns are primary except in certain safety-related circumstances.

Synchronized Mode

In synchronized mode, the injector is pulsed once for each reference pulse from the distributor. To describe it another way, the injector operating in synchronized mode sprays fuel once for each time a cylinder fires. On dual-TBI units, the injectors are pulsed alternately to avoid fuel pressure pulse problems. All closed-loop operation is in synchronized mode, as is most open-loop operation.

Non-Synchronized Mode

In non-synchronized mode, the injector pulses every 12.5 ms, regardless of distributor reference pulses (REF). On dual-TBI systems, each injector pulses every 12.5 ms, but because the injectors pulse alternately, the engine actually "inhales" a fuel spray pulse every 6.25 ms. Non-synchronized pulses occur only in response to one or more of the following operating conditions:

- The injector is on or off (open or closed) and time becomes too small for accurate duty-cycle control (about 1.5 ms), as occurs near full throttle or during deceleration. Even though the injector only opens a few thousandths of an inch, it is a mechanical device opened by a magnetic field and closed by a spring. It has a definite, finite maximum speed in contrast to its virtually instantaneous electric current flow. When the injector is required to open or close at a rate that approaches its mechanical response capacity limit, the PCM stops making the injector keep up with the reference pulse and employs the slower mode of operation.
- During *prime* pulses. On the 1982 Crossfire EFI system, once the ignition was turned on and if the coolant temperature was low enough, the PCM commanded the injectors to deliver a spray or two into the manifold to prime the engine for starting. This action was similar to pumping the throttle before starting a carbureted engine and squirting a small amount of fuel into the manifold using the accelerator pump. The Crossfire system was, however, discontinued in 1983.

Diagnostic & Service Tip

While the purpose of the clear flood mode is to allow the engine to start when flooded, a malfunctioning or completely misadjusted throttle position sensor (TPS) can indicate an 80 percent or wider open throttle even when the driver has not depressed the pedal at all. This condition, of course, prevents starting. This kind of problem most commonly occurs when the TPS loses its ground and cannot reduce the reference signal back to the computer.

Cranking Mode

The fuel injector(s) delivers an enriched air/fuel ratio particularly suited for starting conditions when the starter cranks the engine. These conditions include high manifold pressure and low air flow velocity, both of which make fuel vaporization more difficult. The actual pulse widths depend on coolant temperature. At –32°F (–36°C), the pulse width is calibrated for a maximum rich air/fuel, approximately 1.5 to 1. At 201.5°F (94°C), the pulse width is calibrated for a maximum lean air/fuel ratio, approximately 14.7 to 1. The higher the temperature, the shorter will be the pulse width or injector on-time, unless the engine is overheated, in which case pulse width is widened somewhat to provide a slightly richer mixture, required for starting in that condition.

Clear Flood

If an engine floods (that is, if the spark plug electrodes are damp enough with fuel that the electric pulse grounds through the fuel rather than jumping the spark plug gap, thus misfiring), the PCM adopts the clear flood strategy. Depressing the throttle to 80 percent of wide-open throttle or more during crank causes to the computer to issue an air/fuel ratio of about 20 to 1. It stays in this mixture mode until the engine starts or until the throttle is closed to below 80 percent WOT. If the engine is not flooded and the throttle is held at 80 percent WOT or more, it is unlikely the engine will start with the super lean mixture.

Run

As soon as the PCM sees a reference pulse from the distributor indicating 600 RPM or more, it puts the system into open loop. In open loop the PCM does not use information from the oxygen sensor to determine air/fuel mixture. It monitors the oxygen sensor signal to see whether the system is ready to go into closed loop, but its delivered mixture commands are determined from engine coolant, speed, and load information. The following criteria must be satisfied before the engine can go into closed loop:

- The oxygen sensor must produce voltage signals crossing 0.45 V (450 mV). Before it can do this, the oxygen sensor must have reached a temperature of at least 570°F (300°C).
- The engine coolant temperature (ECT) must reach a specified level, about 150°F (65.5°C). This temperature varies depending on model and build year.
- A specified amount of time must elapse since the engine was started, regardless of component temperatures. This factor also varies by model.

The values for each of these criteria are encoded in the PROM. When all of the criteria are met, the PCM puts the system into closed loop. At this point, the PCM uses the input from the oxygen sensor to calculate fine adjustments to the air/fuel mixture commands. Of course, if one of the other sensors indicates that closed-loop criteria have failed, the PCM will return to open-loop calculations.

Semi-Closed Loop

To improve fuel economy, the PCM for some throttle body injected engines is programmed to go out of closed loop during some sustained cruise conditions at highway speeds. During these periods, the air/fuel mixture may go as lean as 16.5 to 1. The PCM monitors the following parameters and puts the system into this fuel control mode only when they are within predetermined values (varying somewhat by model and year):

- engine temperature
- spark timing
- canister purge
- constant (sustained) average vehicle speed

The PCM periodically switches back to closed loop to check on engine operating parameters. If the parameters are still within the required limits, it goes back to the lean calibration, open-loop mode. Operation in the lean calibration, open-loop mode, and switching back and forth between closed loop and open loop are smooth and should not be detectable to the driver.

INPUTS

Engine Coolant Temperature Sensor

The engine coolant temperature (ECT) sensor used with the EFI version of GM's C3 system is an NTC thermistor that varies its resistance according to changes in its temperature. (See Chapter 3 for additional information on the operation of this sensor.) It is mounted into a coolant jacket, usually near the thermostat housing. As the temperature of the coolant increases, the resistance of the sensor decreases, resulting in a decrease of the voltage drop measurement that the PCM takes across the sensor. Operating within a 0-V to 5-V range, the voltage reading across the sensor is relatively high when the engine is cold and will closely approach about 0.5 V when the engine is at operating temperature. The GM ECT sensor shown in Figure 10–6 is a newer style with an elliptical connector, replacing the one from the early 1980s that had a round terminal connector.

Manifold Absolute Pressure Sensor

The manifold absolute pressure (MAP) sensor used with the EFI version of GM's C3 system is an analog absolute pressure sensor using a piezoresistive silicon diaphragm that varies its resistance as pressure changes cause it to flex. (See Chapter 3 for additional information on the operation of this sensor.) This sensor operates within a 0-V to 5-V range, with a relatively high voltage representing a higher pressure within the intake manifold and a relatively low voltage representing a lower pressure (reduced by applied vacuum) within the intake manifold. Unlike the C3 feedback carbureted systems that used two such sensors—one as a full-time MAP sensor and one as a full-time barometric pressure (BP) sensor—the EFI system uses only one such sensor. This sensor is referred to as a MAP sensor (Figure 10–7) but it is also used by the PCM to update BP values. When the ignition is first turned to run, but before it is turned to start, the PCM takes a reading from the MAP sensor. Since the engine is not running, the manifold pressure is identical to atmospheric pressure. The PCM records this reading as the base barometric pressure and uses it for calculations of fuel mixture while in open loop and for calculating spark timing. This BP reading is retained and used until the engine is restarted or until the throttle is opened

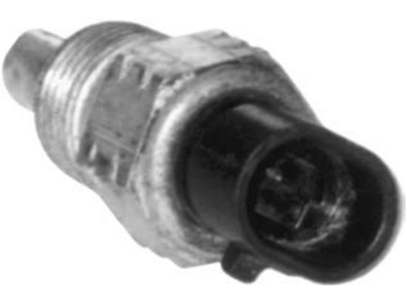


Figure 10–6 ECT sensor.

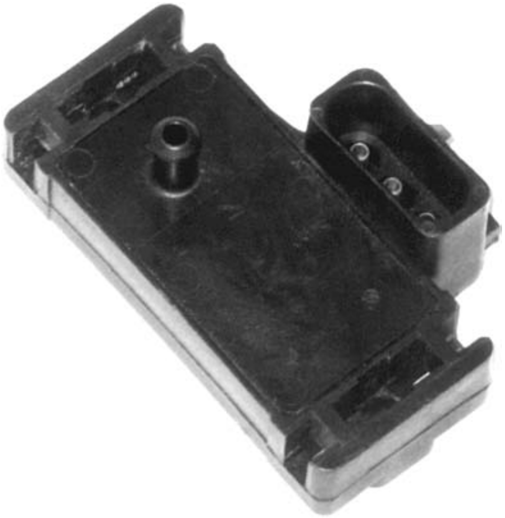


Figure 10–7 MAP sensor.

to WOT. At that time manifold pressure increases to nearly atmospheric pressure and an updated BP reading is taken.

Oxygen Sensor

The oxygen sensor (O_2S) used with the EFI version of GM's C3 system is a single-wire zirconium dioxide sensor (Figure 10–8) that generates a voltage above 450 mV when the residual oxygen in the exhaust indicates a rich condition and less than 450 mV when the residual oxygen indicates a lean condition. (See Chapter 3 for additional information on the operation of this sensor.) The GM version, though, is unique in that the PCM generates a 450-mV signal, which it then places on the oxygen sensor signal wire. This 450-mV signal is known as a *bias voltage.* The PCM places the bias voltage on the oxygen sensor signal wire whenever the engine is started and until the O_2S begins to generate its own voltage. The PCM's voltage-sensing circuits continue to watch this voltage signal. As the engine is warming up, eventually the voltage begins to exceed the 450-mV bias voltage placed on the circuit. At this point the PCM knows that the O_2S is hot enough to begin generating its own voltage and it will then remove the bias voltage signal and watch the voltage that the O_2S is placing on this circuit. Therefore, when watching the O_2S voltage values with a scan tool immediately after a cold engine start, expect to see a value of 450 mV, even before the oxygen sensor is hot enough to operate.

The Cadillac DFI system uses two oxygen sensors, one in each exhaust manifold, allowing the system to control the air/fuel ratio more closely. It can adjust the pulse width on one side of the engine independently of the adjustments on the other side.

Throttle Position Sensor

The throttle position sensor (TPS) is a variable resistor (potentiometer) mounted on the TBI unit, connected to the end of the throttle shaft (Figure 10–9). On some EFI applications the TPS is adjustable; on others there is no way to adjust the TPS. (See Chapter 3 for additional information on the operation of this sensor.) The TPS operates within a 0-V to 5-V range, returning a signal of close to 4 V or better when the throttle is at WOT and returning a signal of about 0.5 V when the throttle is at idle.

Distributor Reference Pulse

The distributor reference pulse, sometimes called the **REF pulse,** tells the PCM what the

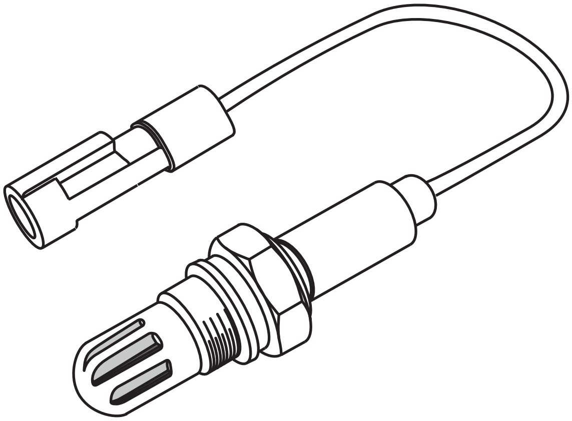


Figure 10–8 Oxygen sensor.

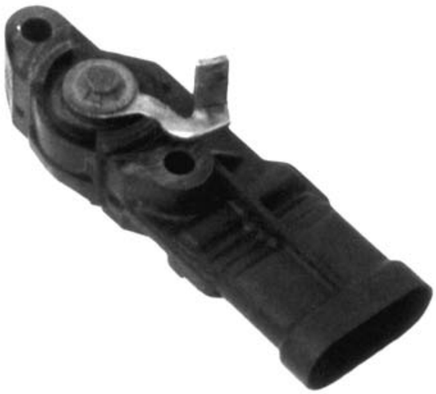


Figure 10–9 TPS.

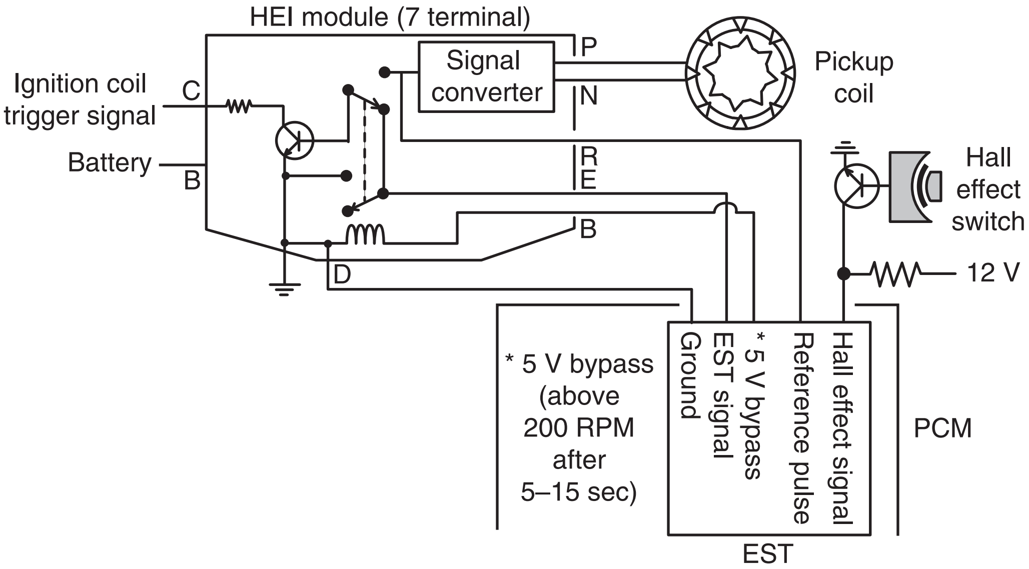


Figure 10–10 High energy ignition (HEI) module with electronic spark timing (EST) and Hall effect switch.

engine speed is (when factored against the PCM's internal clock) and what the crankshaft position is. On most EFI applications, the distributor **pickup coil** provides the REF signal. It is important to note that if the REF signal fails to arrive at the PCM while the engine is running, fuel injection shuts off.

The earlier 2.5-L EFI engines used a Hall effect switch to supply the REF signal (Figure 10–10). The pickup coil at the distributor was retained for starting, but that was its only function.

Detonation (Knock) Sensor

The detonation (knock) sensor used on the EFI version of GM's C3 system is a piezoelectric silicon crystal that generates a signal when excited by vibrations characteristic of knock frequencies (Figure 10–11). It generates an AC voltage frequency in response to engine knock or detonation, and the resulting signal can be read with an AC voltmeter, Hertz meter, or lab scope (DSO). The detonation sensor is an input to an electronic spark control (ESC) module, which retards computed timing in response to a signal from the detonation sensor. The ESC spark retard system is a subsystem of GM's EST system (described later in this chapter).

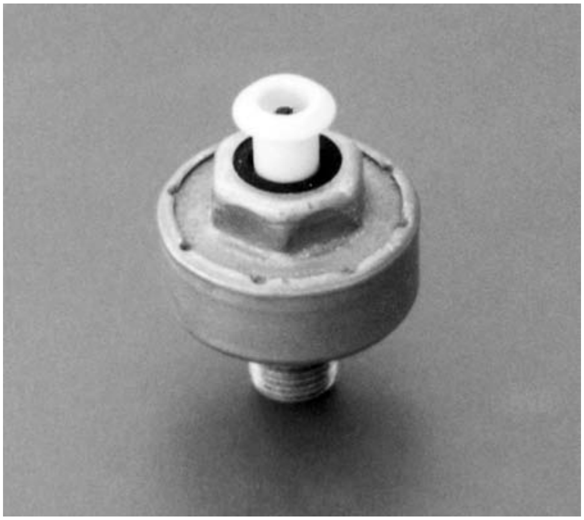


Figure 10–11 Detonation sensor.

Vehicle Speed Sensor

Two kinds of vehicle speed sensors (VSSs) are used on CCC systems. The earlier type uses a **light-emitting diode (LED)** and a phototransistor. Both are in a plastic connector plugged into the back of the speedometer housing near the speedometer cable attachment point (Figure 10–12). On early models, the LED is powered through the PCM; on later versions, power comes directly from the ignition switch. With the ignition on, the LED directs its invisible infrared light beam to the back of the speedometer cup, which is painted black. The drive magnet, spinning with the speedometer cable, has a reflective surface at one point. As the drive magnet moves into the light from the LED, the light reflects back to the receptive phototransistor. Each time the light strikes the phototransistor, it produces a voltage pulse. These pulses are fed to a buffer switch.

The VSS signal is an analog signal, varying in amplitude as well as frequency as the vehicle speed changes. The buffer switch modifies the raw VSS signal to 2002 digital pulses per mile (different pulse numbers in certain later models). The PCM uses this information to determine when to apply the torque converter clutch (TCC).

Some later-model vehicles use an electronically operated speedometer with no speedometer cable. These vehicles use a pulse generator device as a VSS. This device bolts to the transmission where the speedometer cable drive would otherwise be connected. This transmission-driven signal generator rotates a magnet near a coil. As each pole of the magnet swings by the coil, a weak voltage signal, similar to what a magnetic pickup in an ignition distributor generates, is produced in the coil. This signal produces an analog voltage signal proportional to the speed of the car. These signals are fed to a buffer, which converts them to 4004 digital pulses per mile. These signals then go to the PCM, which calculates vehicle speed from the signal frequency and its own internal clock. Four-wheel-drive vehicles often have two similar sensors, one for transmission output and one for vehicle speed, to enable the computer to distinguish when the vehicle is in the low transfer case range.

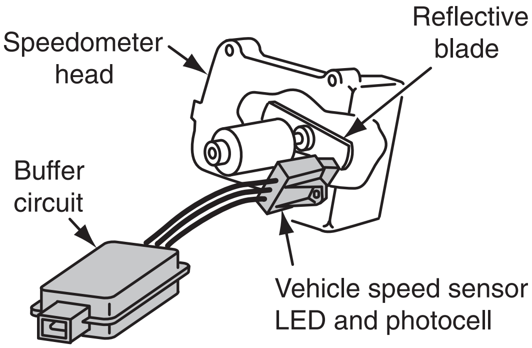


Figure 10–12 Vehicle speed sensor.

Diagnostic & Service Tip

The LED-generated VSS signal can be blocked by anything that can block the infrared light. Either a dust ball or, not infrequently, a ball of grease pushed through the speedometer cable can shut off the signal. Many experienced technicians check this first when there is indication of a VSS signal failure.

Ignition Switch

The ignition switch is one of the two power sources for the PCM. When the ignition is first turned on, the PCM initializes (starts its program boot-up sequence) and is quickly ready to function. The ignition switch also powers most of the actuators that the PCM controls.

Park/Neutral Switch

The park/neutral (P/N) switch, usually part of the shifter assembly, closes when the vehicle is shifted into park or neutral. This provides the PCM with information about whether the vehicle is in an active gear. The PCM uses this information to control engine idle speed. If the P/N switch is disconnected or significantly out of adjustment (enough to signal one gear when it is in another), idle quality can suffer. An out-of-adjustment P/N switch can also prevent engagement of the starter, as had been the case for many years before computer controls.

Transmission Switches

Most transmissions used in C3/EFI vehicles employ one or more hydraulically operated electric switches screwed into the valve body. These switches send the PCM signals indicating what gear the transmission is in. This information allows the PCM to properly control engagement and disengagement of the torque converter lockup clutch.

Air-Conditioning Switch

On EFI cars with air conditioning, the air-conditioning (A/C) switch includes a wire to the PCM. When the A/C is turned on or off, the wire conveys this information to the PCM, which uses the signal in its determination of the proper idle speed.

Ignition Crank Position

The circuit that energizes the starter solenoid also signals the PCM through a wire. This informs the PCM that the engine is cranking, which the PCM uses in determining fuel injection programs for startup.

Fuel Pump Voltage Signal

Some EFI systems have a wire from the power side of the fuel pump (positive) to the PCM. This wire indicates to the PCM that the fuel pump is on (Figure 10–13). Not all vehicles include this feature, however.

OUTPUTS

Throttle Body Injection Unit

The throttle body injection (TBI) unit is made of three castings: the throttle body, the fuel meter body, and the fuel meter cover (Figure 10–14).

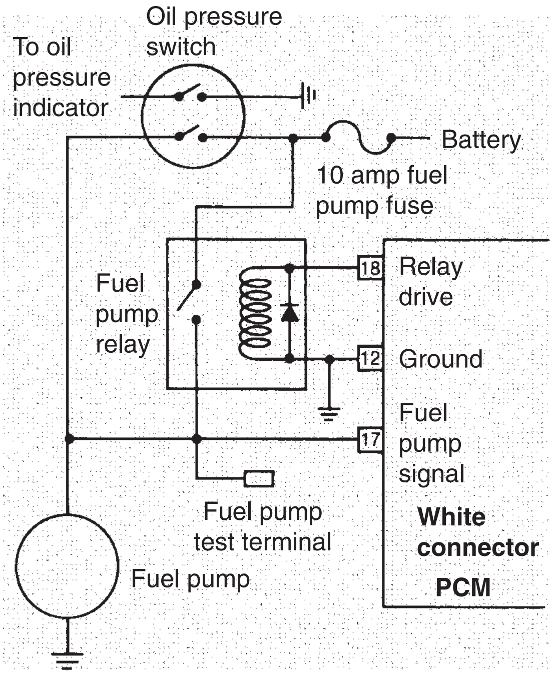


Figure 10–13 Fuel pump control circuit.

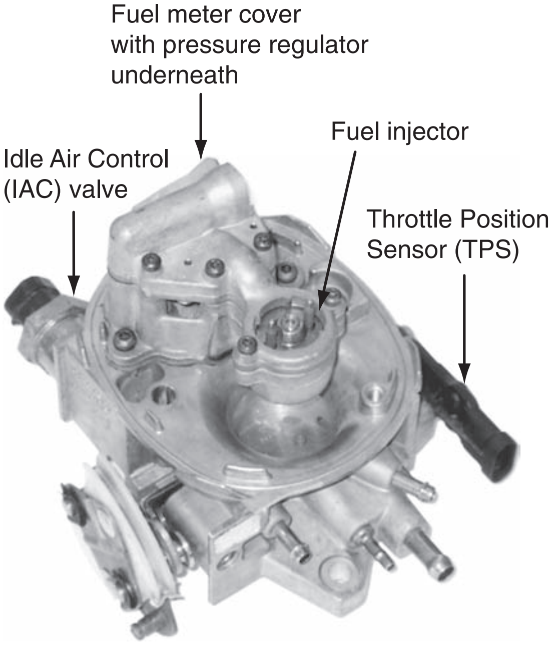

Fuel meter cover with pressure regulator underneath
Fuel injector
Idle Air Control (IAC) valve
Throttle Position Sensor (TPS)

Figure 10–14 C3 TBI unit.

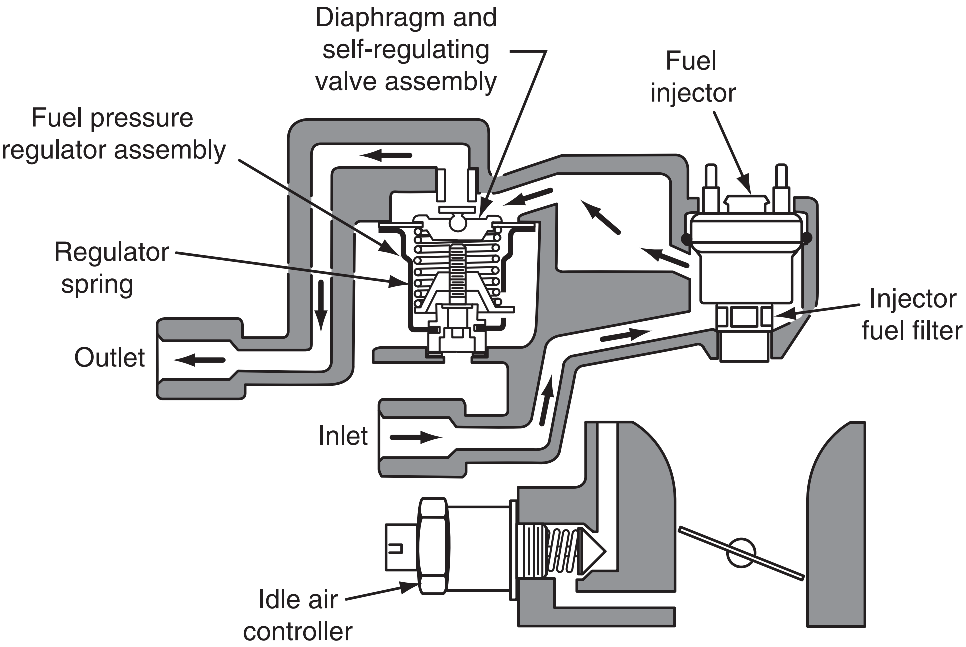


Figure 10–15 Idle air bypass circuit.

The throttle body contains the throttle bore and valve. It provides the vacuum ports for exhaust gas recirculation (EGR), canister purge, and so on, similar to what is found on the base of a carburetor. Mounted to it are the idle air control (IAC) motor and the TPS. The fuel meter body contains the fuel injector and the fuel pressure regulator (Figure 10–15).

Injector Assembly

The injector is a solenoid-operated assembly (Figure 10–16). When energized by the PCM (by the PCM controlling the ground side of the injector), a spring-loaded metering valve lifts off its seat a few thousandths of an inch. Fuel under pressure passes through a fine screen filter fitted around the tip of the injector, spraying in a conical pattern toward the walls of the throttle bore, just above the throttle blade. The angle and position were chosen to maximize the exposure

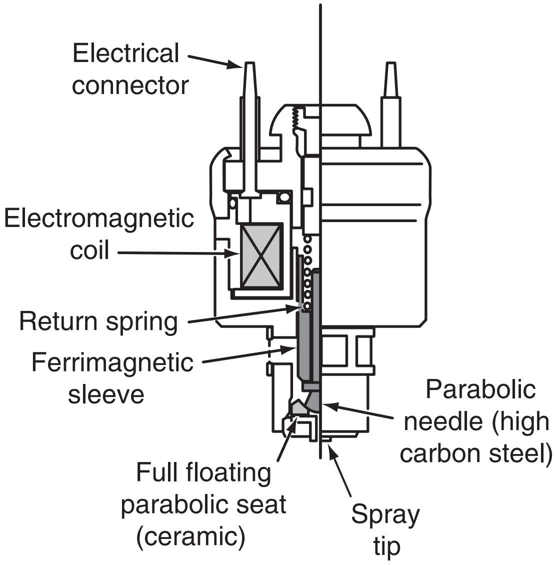


Figure 10–16 TBI fuel injector.

The TBI

The fascinating thing about the EFI system is that the TBI unit performs every function a carburetor does—but with greatly increased control. When the TPS moves rapidly, the injector momentarily sprays more fuel (increased pulse width), just as with an accelerator pump. On cold starts, the injector sprays additional fuel to duplicate the function of a choke. With the idle speed controller, the throttle body achieves fast idle by simply opening the idle control motor. The TBI requires no mechanical choke, fast idle cam, accelerator pump, piston, and so on. Everything is done electronically. Even better than with a carburetor, on deceleration the TBI unit can lean the fuel mixture even to the point of shutting fuel off altogether in some cases. This can compensate for any fuel that evaporates from manifold walls as a result of the momentarily higher vacuum under deceleration. Hard deceleration—a closed throttle, a sharp drop in manifold pressure, and a decrease in vehicle speed—determines the shutoff of fuel.

The major difference is in the control circuits: The carburetor functions as a pneumatic/mechanical/hydraulic computer to meter the air/fuel mixture. The TBI unit, however, is a dumb actuator, responding only to the computer's control commands. It does no controlling itself.

of fuel droplets to onrushing air, thus optimizing vaporization. The angle of injection sprays the fuel droplets across the incoming air as well as into the throttle body, maximizing vaporization by maximizing exposure to passing air.

Fuel Pressure Regulator

Inside the TBI assembly is a fuel pressure regulator (Figure 10–15). The purpose of this regulator is to maintain the fuel pressure within a specified range so that the PCM's pulse-width injection commands will translate into the proper stoichiometric ratio in the combustion chambers. The spring side of the diaphragm is exposed to atmospheric pressure, so fuel pressure varies slightly with changes in atmospheric pressure. At lower atmospheric pressures, the fuel pressure applied to the inlet of the fuel injector is reduced equally as the atmospheric pressure at the outlet tip of the injector is reduced. This keeps the pressure differential across the fuel injector(s) consistent regardless of changes in altitude or weather, ensuring that the flow rate will be consistent any time an injector is energized. Therefore, the only variable used to control the amount of fuel introduced into the engine is the injector's on-time or pulse width. This gives the PCM absolute control of the air/fuel ratio. On the C3 system, fuel pressure should be maintained between 9 and 13 PSI by the fuel pressure regulator. On a Cadillac DFI system, fuel pressure should be between 9 and 12 PSI.

On a Crossfire system used with the C3 system, the rear TBI unit has the pressure regulator, while the front TBI uses a pressure compensator (Figure 10–17), which works like the regulator except that its function is to make up for the temporary drop in fuel pressure between front and rear units and to keep the pressure identical at both. Such drops are usually caused by the diaphragm and valve in the pressure regulator moving to a more closed position, thus allowing less fuel to the front unit.

Idle Speed Control

There are two forms of idle speed control (ISC) used in General Motors TBI systems—the Cadillac DFI system used a DC motor that manipulated the physical position of the throttle plates, thus controlling air flow, and the C3 system used a stepper motor that controlled throttle bypass air without adjusting the physical position of the throttle plates.

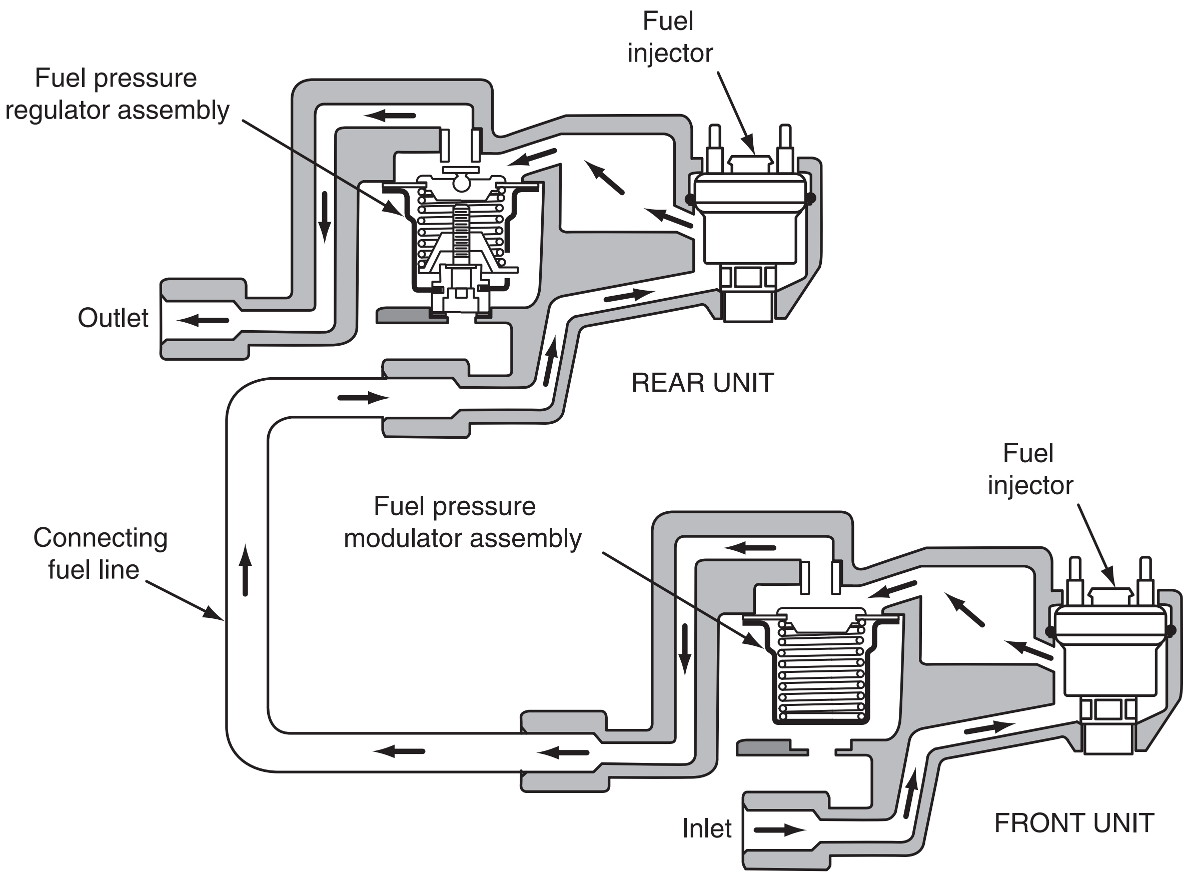


Figure 10–17 Crossfire TBI units.

DC Motor: DFI System. The PCM controls the engine's idle speed through a reversible DC motor called an ISC motor that is mounted on the side of the dual-injector throttle body (Figure 10–18); this is essentially the same motor used with General Motors C3 system feedback carburetors, having carried over to the TBI system used with the Cadillac DFI system. The ISC motor assembly has four electrical terminals, two of which serve as the PCM's control circuit of the motor and two of which serve as a monitored switch input to the PCM (Figure 10–19).

If the PCM wants to increase idle RPM, it applies a power and ground in the correct polarity to cause the plunger to extend against and push on the throttle lever, thus opening the throttle. To reduce idle RPM, the PCM reverses this polarity and retracts the plunger, thus allowing the throttle plates to close up. When this assembly was used with C3 system feedback carburetors to control idle speed, the physical movement of the throttle plates controlled both air and fuel delivery. In the DFI application, the opening and closing of the throttle plates only controls air flow. It is up to the PCM to adjust the injectors' pulse width to add or subtract fuel to control the engine's idle RPM.

The switch, sometimes referred to as a *nose switch* or *idle tracking switch,* simply informs the PCM when it is the PCM's responsibility to

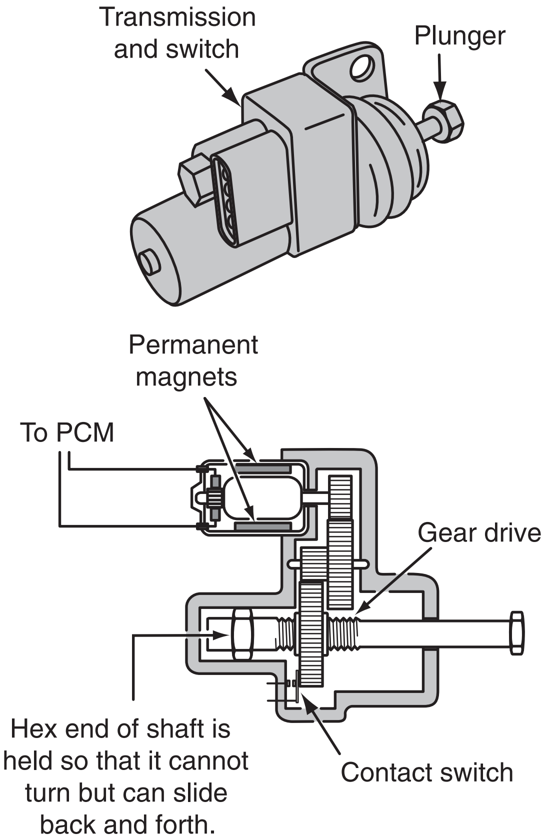

Transmission and switch
Plunger
Permanent magnets
To PCM
Gear drive
Hex end of shaft is held so that it cannot turn but can slide back and forth.
Contact switch

Figure 10–18 ISC motor.

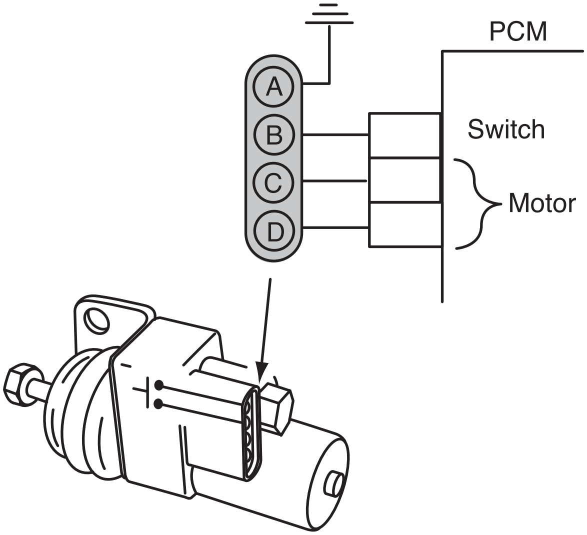


Figure 10–19 ISC motor connector.

control idle speed. When the driver depresses the throttle pedal, the throttle lever lifts off the switch, allowing it to open electrically, at which point the PCM extends the plunger outward. When the driver releases the throttle pedal, the throttle lever comes back against the switch with enough force to override the switch's light spring and the switch closes electrically. At this point, the PCM retracts the plunger gently enough to avoid engine stall (acting like the dashpot of earlier years) and begins controlling idle speed. If, when the driver releases the throttle pedal, the throttle lever does not come back with enough force to close the spring-loaded switch (due to a sticking throttle shaft or weak throttle return spring), the PCM will hold the idle RPM too high.

The PCM uses information from the following sensors and switches to control throttle plate position in any of the three operational modes (some of these are inputs that identify the operational mode):

- VSS
- TPS
- Idle tracking switch
- Ignition tach reference signal
- A/C clutch signal
- ECT signal
- MAP sensor signal
- P/N switch
- Ignition switch

During engine crank and initial warm-up, the throttle plates are held in a predetermined position. Once the engine starts, the throttle is held in a fast idle position to allow intake manifold conditions to stabilize. If the engine is started hot, the fast idle period will be very short. If the engine is started cold, the fast idle period will be longer and will be maintained until the engine reaches normal operating temperature.

When the engine is idling at normal operating temperature, curb idle is maintained at a predetermined speed. If engine load changes because of the A/C clutch cycling on and off, the transmission going into gear or neutral, or because of momentary high power-steering pressure load, the PCM adjusts the throttle opening to maintain the predetermined engine speed.

During deceleration, manifold pressure goes very low (or intake manifold vacuum goes very high, an equivalent description), and any liquid fuel in the manifold evaporates very quickly in the reduced pressure. This will result in a very rich air/fuel mixture and high HC and CO exhaust emissions unless enough air is let into the manifold to mix with the fuel vapors, as well as to reduce the vacuum. The PCM uses information from the VSS and MAP sensors to calculate the degree of deceleration and determine how much throttle opening is required to prevent the rapid fuel evaporation. During very hard deceleration, for example, such as if descending a hill when second gear has been manually selected, the PCM can shut off the fuel injectors completely.

Idle Air Control: C3 System. The idle air control (IAC) assembly controls idle speed by controlling the amount of air bypassing the throttle. It consists of a small, reversible electric stepper motor and a pintle valve (Figure 10–15). As the motor's armature turns, the pintle valve extends or retracts depending on the direction the motor is turning. During idle, the throttle blade is in a fixed, nearly closed position, allowing a constant amount of idle air into the intake manifold. The pintle valve allows additional air through the bypass passage. The PCM uses the stepper motor to position the pintle valve for desired idle speed. During warm engine operation, the PCM attempts to maintain a fixed idle speed by adjusting the IAC valve position for load variations (transmission in or out of gear, air conditioner on or off, and so on).

If, during idle or at low vehicle speed (below 10 mph), engine speed drops below a specified RPM, the PCM puts the IAC into anti-stall mode. The IAC motor retracts the pintle to allow additional air into the intake manifold to raise engine speed. It momentarily raises engine speed above base idle.

The stepper motor is unique: its armature has two separate windings. The direction in which the armature turns depends on which winding is powered. Power is applied by the PCM in short pulses. Each pulse rotates the armature about 30 degrees and extends or retracts the pintle valve a corresponding amount. The PCM applies as many pulses as necessary to set the valve where it will achieve the desired idle RPM.

The PCM counts the pulses applied and thus knows where the pintle valve is at all times. There are 12 pulses per revolution and 256 possible positions (including fully closed). IAC counts are shown on a scan tool in the data stream to indicate how far between open and closed the PCM is commanding the stepper motor. Fully extended (closed bypass passage) is the reference position and will display on a scan tool as count "zero." Fully retracted (wide-open bypass passage) is displayed as count "255."

To keep an accurate track of the IAC assembly's position, the PCM references itself frequently. When the engine comes off idle and the car starts to move, the PCM begins looking for a reading from the VSS representing 30 mph. The first time it sees a 30-mph signal, it moves the pintle to the park (fully closed) position to re-identify the zero position. It then moves the pintle to a preprogrammed distance from closed. If for any reason the VSS is disabled, the PCM will not be able to re-establish the correct idle speed.

Fuel Pump Control

Fuel and fuel pressure are supplied by an electric pump inside the fuel tank. The fuel pump assembly contains a check valve preventing the fuel from bleeding back from the fuel line into the tank. If the check valve leaks, the engine cranks longer before starting, while the fuel line is purged of vapor.

The fuel pump turns on and off through a fuel pump relay, usually mounted in the engine compartment. The fuel pump relay is controlled by the PCM. Be aware that the fuel pump relay is identical in appearance and usually mounted beside the A/C relay, also controlled by the PCM

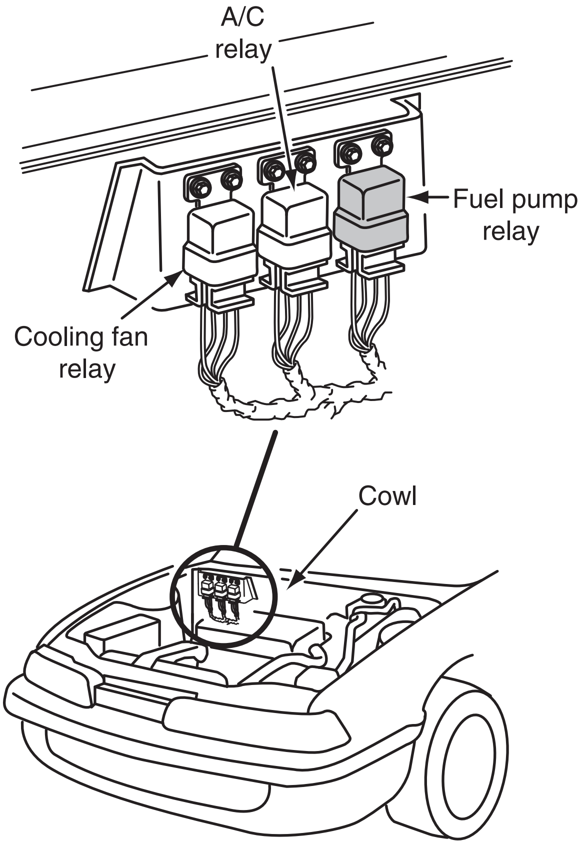


Figure 10–20 Fuel pump, A/C, and cooling fan relays.

(Figure 10–20). On some models, the cooling fan relay is also mounted in the same location and looks just like the other relays.

When the ignition is turned on, the PCM activates the fuel pump relay. If the PCM does not get an ignition tach reference signal within 2 seconds, it turns off the fuel pump by de-energizing the relay and does not turn it back on until it does receive the tach reference signal. If the ignition is turned off, or if the tach reference signal disappears from the PCM for any other reason, the PCM de-energizes the fuel pump relay.

Note also that the oil pressure switch, which operates the oil pressure indicator on the instrument panel, is in parallel electrically with the fuel pump relay. This is done to provide a backup to the fuel pump relay. In the event of a fuel pump relay failure, the oil pressure switch will apply power to the fuel pump when it senses about 4 PSI of oil pressure.

Fuel Pump Test Terminal. A wire connects to the circuit powering the fuel pump. The open end of this wire has a terminal to which a jumper lead can be connected to power the fuel pump. A voltmeter connected to the test terminal quickly shows whether either the fuel pump relay or oil pressure switch is supplying power to the fuel pump circuit. This terminal is located in the engine compartment or in the ALDL under the instrument panel, depending on the model and year.

Voltage Correction. During vehicle operation, system voltage can vary considerably as a result of the various electrical accessories being on or off and the state of the battery's charge. Variations in the system's voltage can cause differences in the amount of fuel delivered at the injectors because of differences in the amount of time the injectors are open (a higher voltage opens the injector more quickly and vice versa). This affects the amount of fuel injected during a pulse width. Because of this problem, the PCM monitors system voltage and multiplies the pulse width by a voltage correction factor programmed into its permanent memory. As system voltage goes down, the pulse width increases. As system voltage goes up, the pulse width decreases. If voltage goes down to a criterion value, the PCM increases dwell to maintain good ignition performance by keeping the spark hot and by increasing the idle speed.

Electronic Spark Timing

Electronic spark timing (EST) maintains the optimum spark timing under all conditions of engine load, speed, temperature, and barometric pressure. Two basic functions are incorporated in the system. Dwell control is provided to allow sufficient energy to build the magnetic field in the ignition coil for proper ignition voltage secondary output. Spark is provided at just the right time to start combustion at the moment of peak pressure

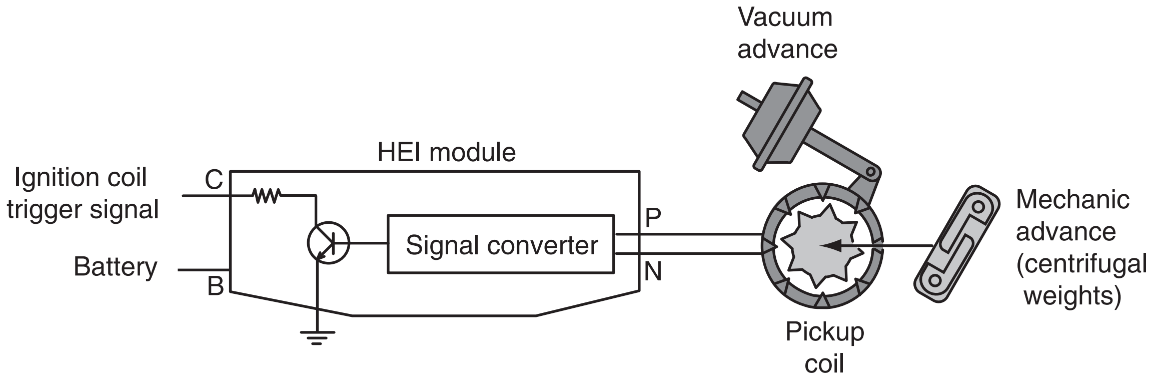

Vacuum advance
HEI module
Ignition coil trigger signal
C
Battery
B
Signal converter
P
N
Mechanic advance (centrifugal weights)
Pickup coil

Figure 10–21 HEI circuit with centrifugal and vacuum advances.

in the compression stroke. The EST function of the PCM eliminates the vacuum and centrifugal advance mechanisms of the classic distributor (Figure 10–21). The HEI module accepts spark timing commands from the PCM once the engine is started.

During engine crank, the solid-state switching circuit in the High-Energy Ignition (HEI) module connects the base of the main switching transistor to the pickup coil (Figure 10–22). The pickup coil signal turns the main switching transistor on and off. This state is called *module mode* and provides no spark advance; the timing is fixed at base timing. This same signal, after it is converted from an analog signal to a digital signal by a signal converter circuit in the module, is also sent to the PCM as the REF signal. During this time, the PCM sends a spark timing command back to the ignition module known as the EST signal, one command signal for every

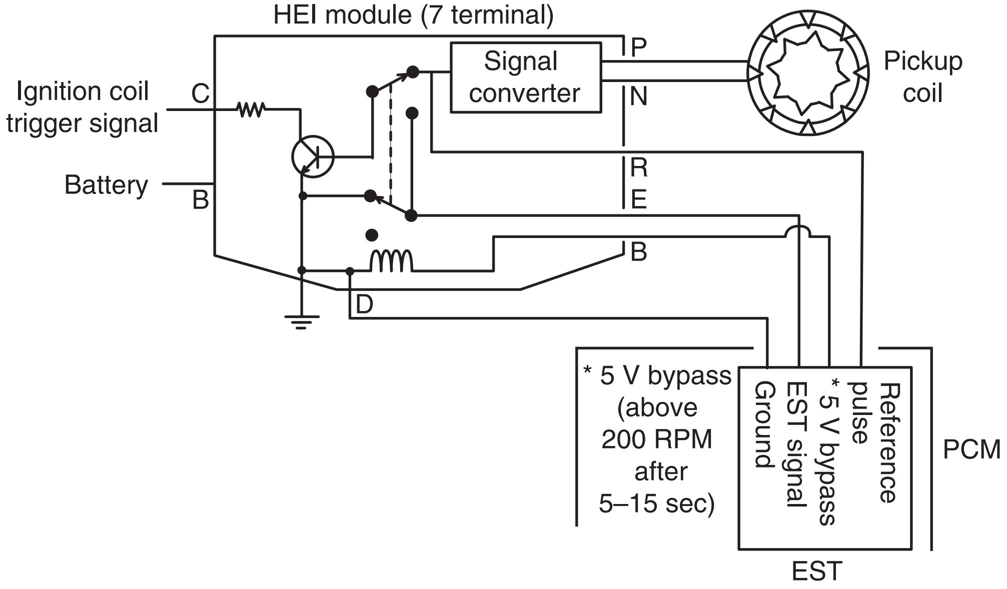


Figure 10–22 HEI module with EST.

base timing signal except that it is advanced in time. During engine crank, the EST signal is not used by the ignition module, but, rather, is grounded out.

When the PCM sees a REF pulse signal corresponding to an engine speed over 200 RPM, it decides that the engine is running. It then sends a 5-V signal over the bypass circuit to the ignition module. The HEI module responds by disconnecting the base of the main switching transistor from the pickup coil and reconnecting the transistor's base to the EST signal. Simultaneously, the EST signal is disconnected from ground. The system is now in *bypass mode,* and the ignition module is controlling the ignition coil according to the computed timing command from the PCM. The PCM considers barometric pressure, manifold pressure, coolant temperature, engine speed, and crankshaft position when determining the computed timing signal.

Electronic Spark Control

Engines with a strong potential for spark knock (particularly higher performance engines) are equipped with Electronic Spark Control (ESC). The ESC system becomes a subsystem of the CCC system on the vehicle. It has its own electronic module working in conjunction with the PCM. Its function is to retard ignition timing when detonation (uncontrolled, rapid burning of the fuel charge) occurs. Two slightly different versions of ESC systems have been used.

Of the two ESC systems, the 1981 system (Figure 10–23) passes the EST and the bypass commands from the PCM through the ESC module on their way to the HEI module. If there is spark knock (as reported by the knock sensor), the detonation sensor informs the ESC module that it is occurring. The ESC module then modifies the EST command. Spark timing is retarded about 4 degrees per second until the detonation clears up. When the detonation sensor no longer "hears" a knock, the ESC module begins restoring the spark advance it took away. The spark advance is restored at a slower rate than it was removed, approximately 2 degrees per second.

In the second version, used on model-year 1982 and later vehicles (Figure 10–24) the EST

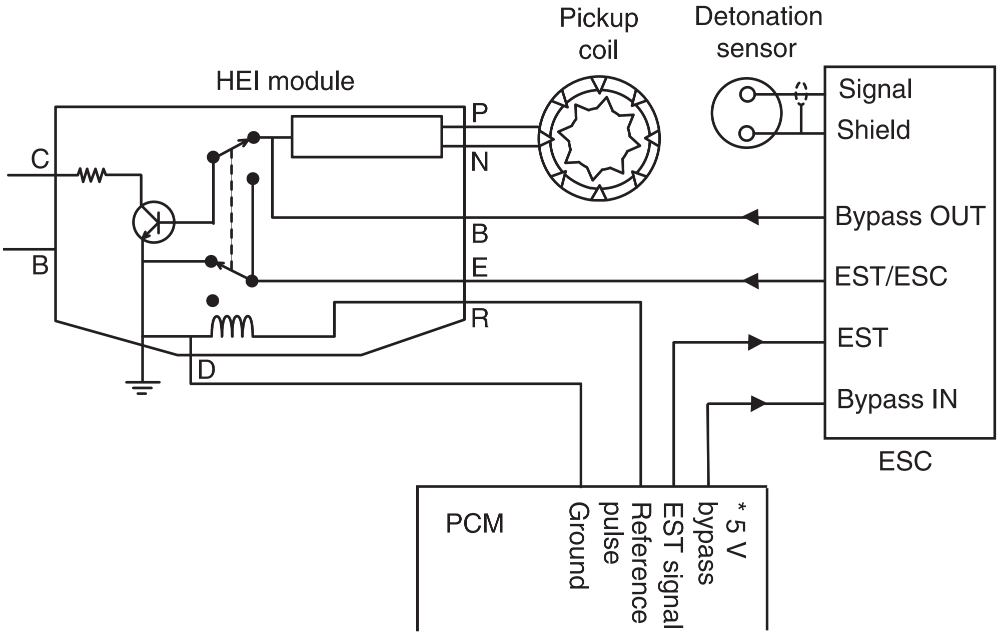


Figure 10–23 ESC circuit, pre-1982.

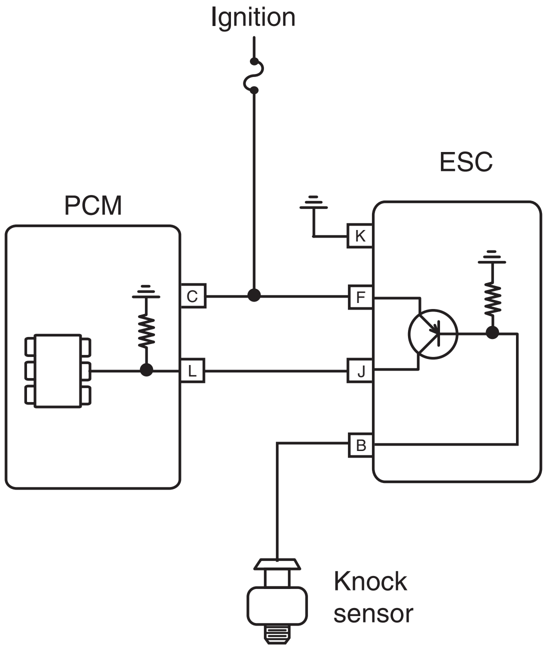


Figure 10–24 ESC circuit.

and bypass commands do not pass through the ESC module. Instead, when the knock sensor produces a voltage indicating knock, the ESC module sends a request to the PCM for it to retard timing. Here is how it works: Ignition voltage is applied to terminal F of the ESC module. The module transfers this voltage, reduced to about 10 V, to terminal J. It is then carried to terminal L of the PCM. When a detonation signal is sensed on terminal B of the ESC module, the module reduces the voltage at terminal J to below 1 V. The PCM then retards timing until the signal voltage reappears at terminal L. Either of the ESC systems can easily be tested by tapping on the intake manifold adjacent to the knock sensor with a metal tool, while watching the timing with a timing light or meter. Be sure to consult the vehicle's appropriate service manual for specific directions.

Torque Converter Clutch

On some C3 and DFI systems, a torque converter clutch (TCC) is used to eliminate the

Knock, Detonation, and Pre-Ignition

Detonation, knock, and pre-ignition are sometimes confused. Each of them involves effectively over-advanced timing, which detracts from engine performance, sometimes also causing damage if the condition persists. Ordinarily the air/fuel mixture burns rapidly but gradually (over about 0.003 second), proceeding from the spark plug and consuming the mixture in the combustion chamber. Detonation occurs if conditions in the combustion chamber reach such a combination of temperature and pressure that the entire charge explodes almost instantaneously. In this case, there is an extremely rapid buildup and loss of combustion pressure, doing little torque-generating work. Detonation can easily occur if the spark advance is too great; the explosion tries to force the piston back down the cylinder at the end of the compression stroke. A high-compression engine is more inclined to detonation than a low-compression engine, because it has much more heat and compression at the top of its compression stroke. An engine with combustion chamber deposits (which displace empty space and have the effect of raising the compression ratio) will have the same problem. These carbon deposits can also glow red hot and become a source of mistimed ignition. In fact, since detonation also builds up deposits (because the fuel is incompletely burned), it can accelerate this problem.

Pre-ignition occurs when a hot spot in the combustion chamber, either a hot exhaust valve or a hot carbon deposit, ignites the air/fuel mixture before the proper time. An engine that diesels after it is shut down is suffering from pre-ignition. The effect is the same, but retarding spark on an engine with a combustion chamber hot spot obviously will not change the ignition point. The only repair for that condition is removal of the deposit or repair or replacement of the defective valve.

hydraulic slippage within the torque converter during cruise conditions.

The TCC is a hydraulically actuated lockup clutch inside the transmission's torque converter. Once a cruise speed is achieved, the TCC is energized. When energized, the TCC eliminates the slippage in the torque converter, which, in turn, improves the vehicle's fuel economy during cruise. This also reduces the heat produced within the torque converter, thus extending the life of the transmission fluid. When the lockup clutch is released, the torque converter works normally (although on some vehicles, engineers have used a torque converter with more converter slip than normal to maximize torque multiplication and smoothness, knowing they could eliminate all the slip once the vehicle was underway at cruise speed). Application and release of the clutch are controlled by the PCM.

The major component of the TCC system is the lockup clutch itself. It becomes a fourth element added to a conventional torque converter (Figure 10–25). The clutch plate, splined to the turbine, has friction material bonded to its engine side near its outer circumference. The converter cover has a machined surface just inside, where the converter drive lugs attach. This machined surface mates with the friction material on the disc when the clutch is applied. When hydraulic pressure is applied to the turbine side of the disc, the disc is forced against the converter cover. The friction between the clutch's friction material and the cover locks up the unit and causes the torque converter to rotate as a solid unit. The pressure source is converter feed oil coming from the pressure regulator valve in the transmission valve body. In non-TCC applications, converter feed oil is used to charge and cool the converter by circulating through the converter and then the

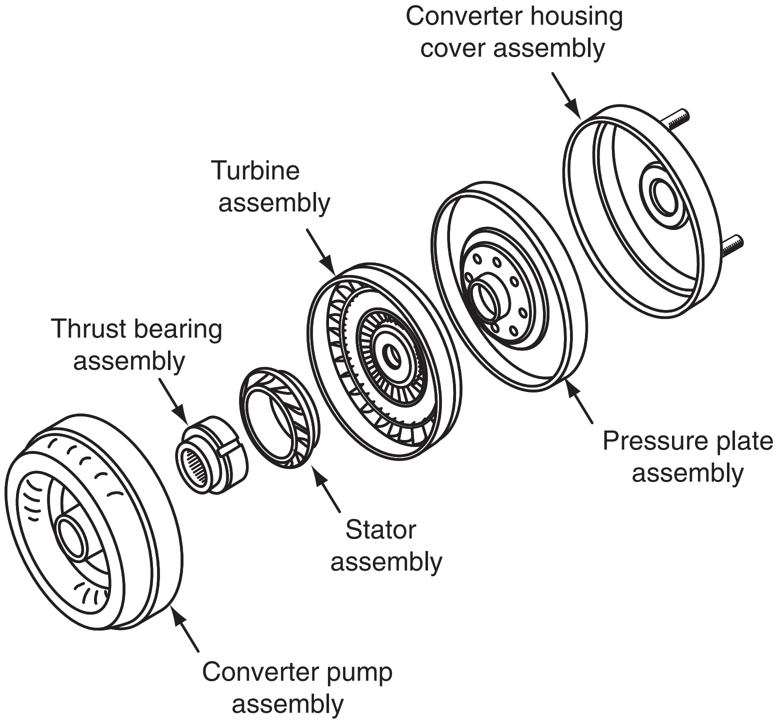


Figure 10–25 Torque converter with TCC.

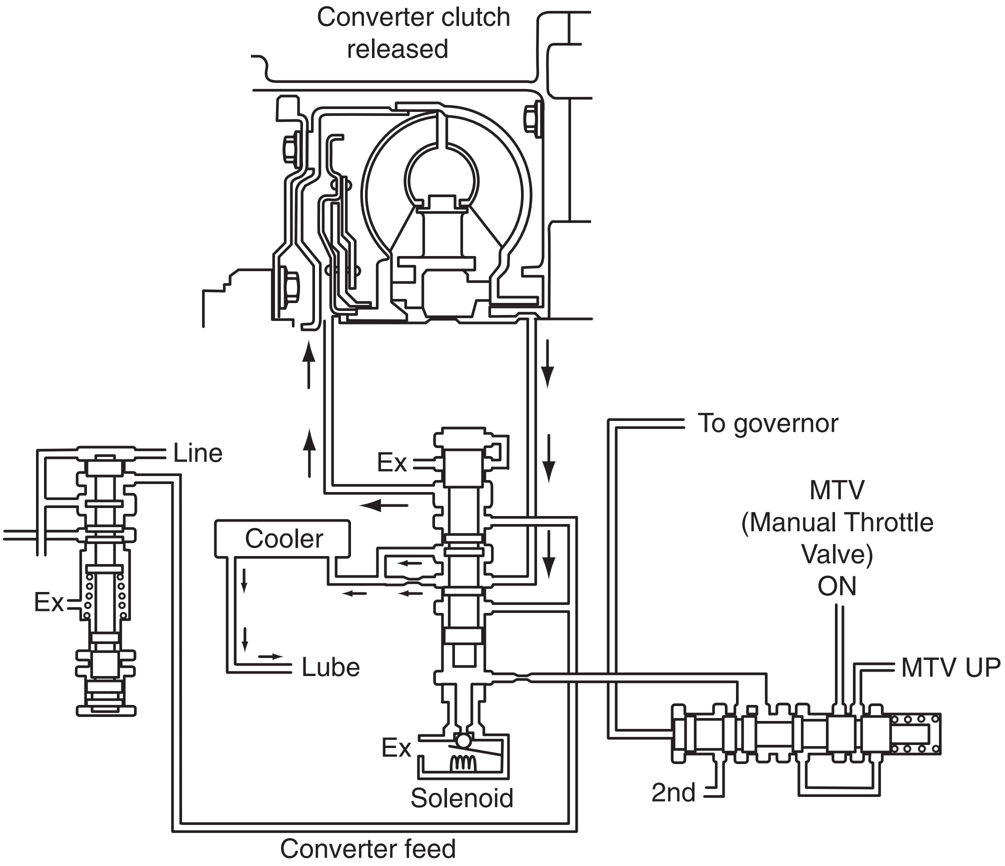


Figure 10–26 TCC apply circuit in release position.

transmission cooler in the radiator. On TCC applications, however, converter feed oil must pass through a converter clutch apply valve on its way to and from the converter. The apply valve, a small valve in the transmission, controls the direction of oil flow through the torque converter (Figure 10–26).

With the apply valve in its at-rest position and the transmission in neutral, or with the vehicle moving at low speed, converter feed oil is directed into the converter through the release passage by way of the hollow turbine shaft. This oil is fed into the converter between the converter cover and the clutch disc. The oil forces the disc away from the cover and thus releases the clutch. Converter feed oil flows over the circumference of the disc and circulates through the converter. It exits through the apply passage, a passage between the pump drive hub and the stator support shaft.

Two criteria must be met before the clutch applies: The transmission must be ready hydraulically, and the PCM must be satisfied with engine temperature, throttle position, engine load, and vehicle speed. When the transmission is in the right gear (this varies from transmission to transmission), hydraulic pressure is supplied at one end of the clutch apply valve (Figure 10–27). This hydraulic pressure (converter apply signal) has the potential to move the apply valve into the apply position. The apply valve is moved, however, only if the PCM is ready for the lockup clutch to engage.

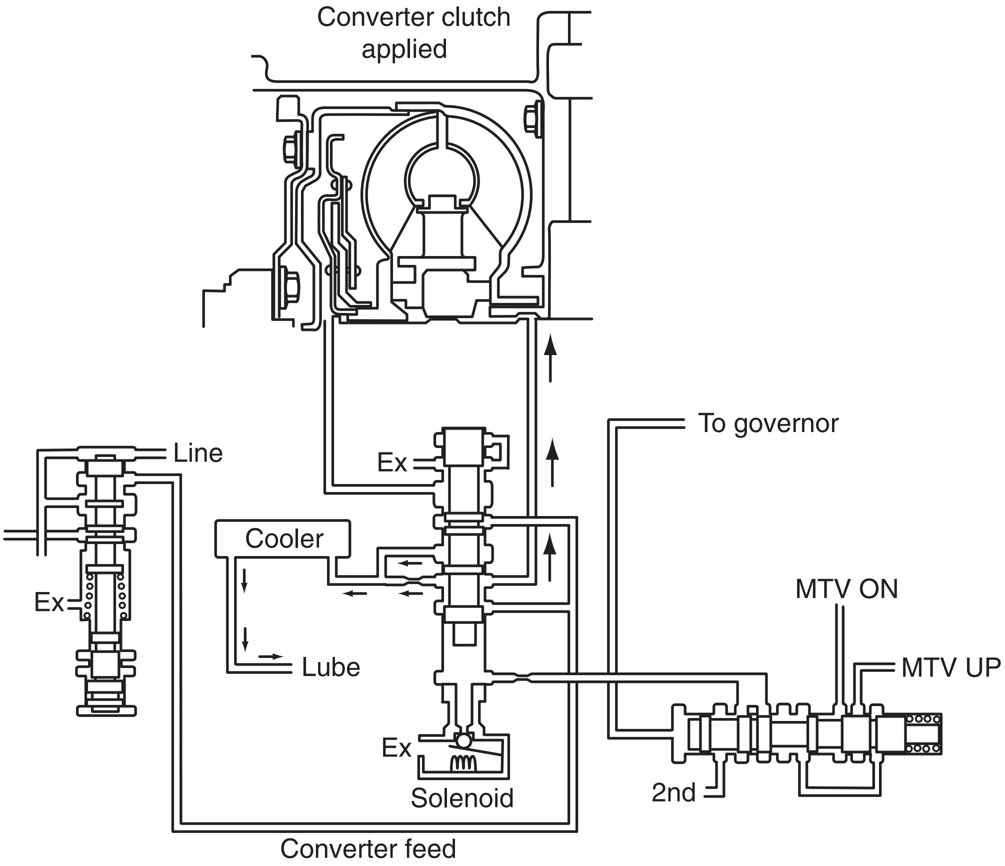


Figure 10–27 TCC apply circuit in apply position.

The PCM controls the position of the clutch apply valve with a solenoid that opens or closes an exhaust port at the converter apply signal end of the apply valve. If the solenoid is not energized, the exhaust port is open and the converter apply signal oil exhausts from the signal end of the apply valve as fast as it arrives, and sufficient pressure does not develop to move the apply valve. Converter feed oil continues to flow into the converter through the release passage (Figure 10–26). When the solenoid is energized, the exhaust port is blocked. The converter apply signal oil develops pressure, and the apply valve moves and is held in the apply position. Converter feed oil now flows into the converter through the apply passage (Figure 10–27). The clutch is applied and prevents oil from exhausting through the release pressure, holding static pressure.

Figure 10–28 shows a typical TCC solenoid control circuit. The power source is the ignition switch, through the gauge fuse. The brake switch is in series on the high-voltage side of the circuit. Any time the brakes are applied, the solenoid is de-energized. After the current passes through the apply solenoid, it arrives at the 4–3 pulse switch, used only on automatic transmissions with a fourth-speed overdrive. The 4–3 pulse switch momentarily disengages the TCC to allow

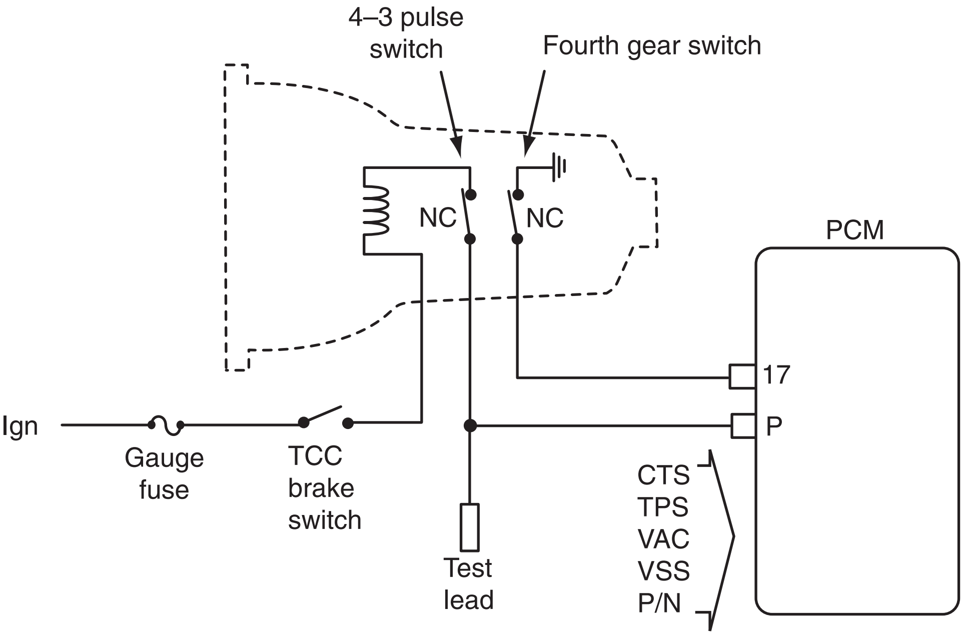


Figure 10–28 TCC electronic control circuit.

a smooth 4–3 downshift. It is closed at all other times. From there, the current goes to the PCM, where the circuit is grounded when the PCM is ready to apply the TCC. When the transmission goes into fourth gear, the fourth-gear switch opens to alert the PCM that the transmission is in overdrive. In overdrive the PCM holds the TCC on through a much wider range of throttle position than it does in second or third gear. To put it in engineering language, the PCM holds the TCC on throughout a wider throttle position window. The term *window* refers to a range within a range. For instance, if the TPS signal to the PCM were 0.5 V at idle and 4.5 V at WOT, the PCM might select 2.0 to 3.5 as the window in which it would keep the TCC applied.

The TCC test lead, which comes from the low-voltage side of the circuit, can be used to tell when the PCM has electrically applied the TCC circuit or to ground the circuit and thus override the PCM. Its use is covered in more detail under "System Diagnosis and Service" later in this chapter.

Viscous Converter Clutch

The viscous converter clutch (VCC), introduced on the 1985 Cadillac front-wheel-drive C-body cars, works the same way the TCC does, except that it does not provide a 100 percent lockup between the engine and the transmission input shaft. It allows a smoother apply and release than the TCC. The VCC clutch is made up of a rotor sandwiched between two parts, called the *cover* and the *body* (Figure 10–29). The rotor and body surfaces facing each other have a series of fins that mesh together with a small space between each fin (Figure 10–30). The effective distance between them is very small, and the shared area is very large. This space is filled with a viscous silicone fluid that drives the rotor. When the VCC is applied, it allows about 40 RPM slippage at 60 MPH, just enough to eliminate some of the torsional vibration between the engine and the transmission. The viscous clutch lockup is controlled the same way as a TCC clutch, except that transmission fluid temperature plays a larger role in its control.

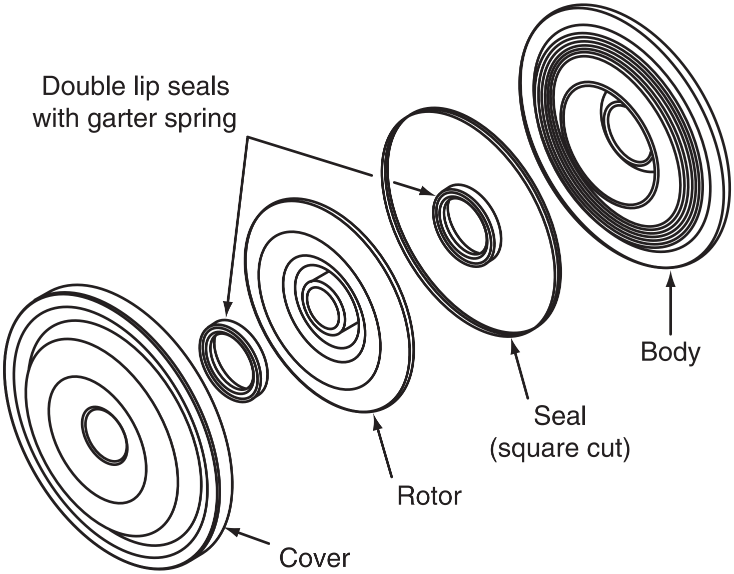


Figure 10–29 Viscous converter clutch (exploded view).

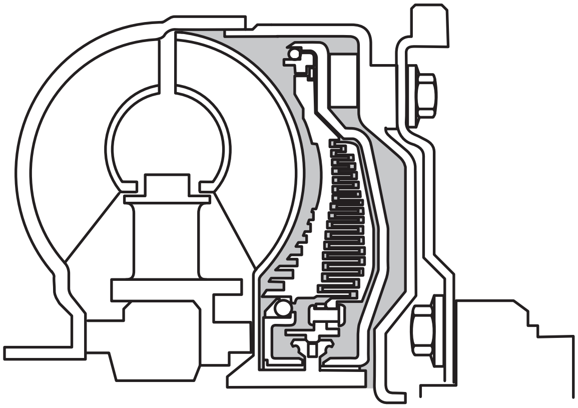


Figure 10–30 Viscous converter clutch.

TCC/VCC Control Parameters

The PCM grounds the TCC/VCC apply solenoid circuit when:

- The criterion speed is reached according to the vehicle speed sensor (VSS). On some cars this can be as low as 24 to 36 mph, depending on throttle position and transmission oil temperature.
- The engine has reached normal operating temperature. If the engine coolant temperature (ECT) is 64°F (18°C) or more when the engine starts, the PCM will apply the converter clutch when the coolant reaches 140°F (60°C) for VCC vehicles. If the coolant is colder than 64°F at startup, the PCM uses a fixed time delay before applying the clutch. The purpose of this delay is to improve low-temperature driveability until conditions allow lockup.
- The TPS signal is within a predetermined window that varies depending on what gear the transmission is in, among other factors. The TPS signal is compared to the vehicle speed signal and the PCM selects different apply speed thresholds for different combinations of TPS and VSS.

Two other signals can disengage the lockup clutch on VCC vehicles: the brake switch and the over-temperature protection switch

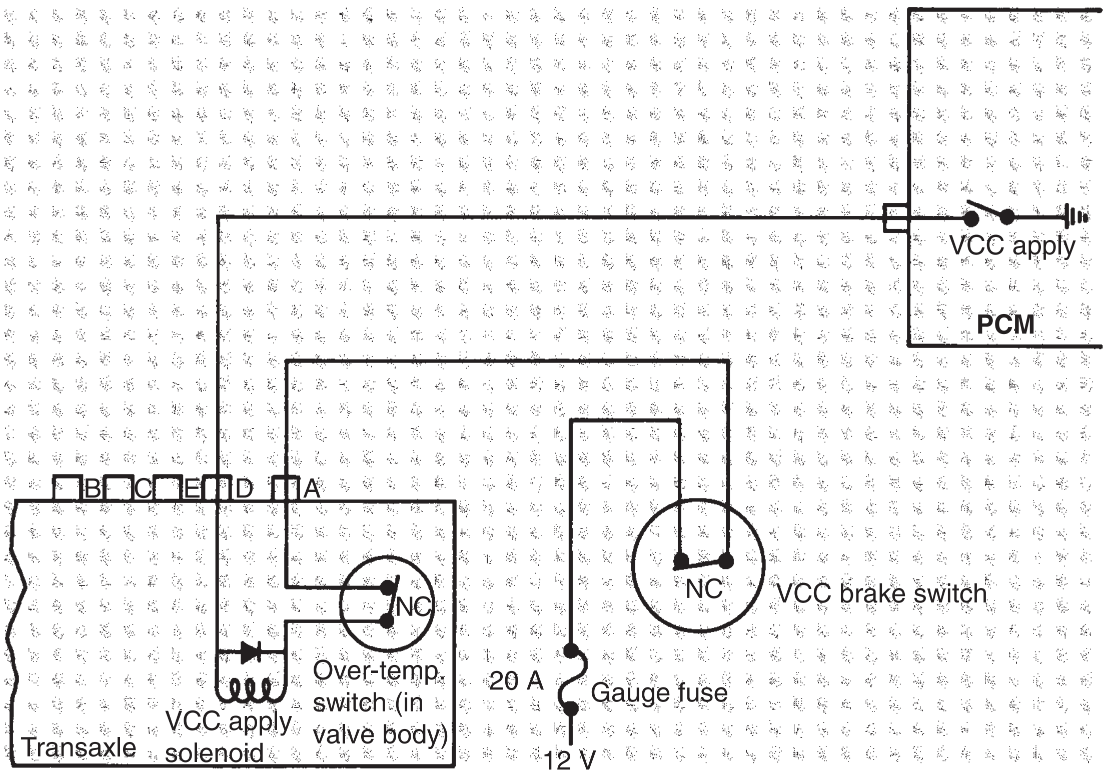


Figure 10–31 VCC electrical control circuit.

(Figure 10–31). Most TCC applications do not use an over-temperature switch. These switches are not controlled by the PCM but are in the apply solenoid circuit. Each must be closed before the circuit can operate. Both are normally closed during driving operations; but if the brake switch is opened when the brake is depressed or the over-temperature protection switch opens (when the transmission oil temperature exceeds 315°F or 157°C), the lockup clutch disengages.

On the 1987 and later Allante, the PCM also controls the transmission 2–3 and 3–4 shifts. The PCM does this through two solenoids it controls in the transmission's valve body. The solenoids block or open passages, allowing oil to move under pressure to the 2–3 and 3–4 shift valves.

Manual Transmissions

On manual transmissions, the TCC output terminal on the PCM can be used to operate the upshift light on the instrument panel. The PCM looks

TCCs and Four-Speed Automatic Transmissions

On vehicles using a four-speed automatic transmission, the TCC must be applied while the transmission is in fourth gear. Any failure resulting in the clutch not applying during prolonged fourth-gear operation can result in transmission damage as a result of oil overheating. This can occur in a relatively short period of steady-state fourth-gear operation.

at engine speed, engine load, throttle position, and vehicle speed. Then it alerts the driver when to shift into the next gear for optimum fuel economy. Note that this shift point is strictly defined for purposes of fuel economy, not for maximum engine life.

Cooling Fan Control

Transverse engines almost universally use an electrically powered radiator cooling fan to pull air through the radiator and across the fins when they are moving at speeds too low for ram air to provide sufficient cooling. On most EFI systems, the PCM has some control over the cooling fan operation. The cooling fan can be turned on either by the PCM itself or by a coolant temperature switch. On some applications, the PCM has full control. The fan is turned on and off by a relay operated by the PCM (Figure 10–32). On most vehicles the fan turns on when the coolant temperature is high, when the vehicle is traveling below 30 MPH with the air conditioner on, and in some cases when the air-conditioning (A/C) high-side pressure reaches a certain criterion point.

Hood Louver Control

The Crossfire EFI system includes an electrically operated air door that the PCM can open using a relay and solenoid. When the hood louver door opens, it allows fresh air from above the engine hood through a hole in the top of the air cleaner housing to the air cleaner elements. The PCM opens the hood louver door above a specified coolant temperature or under WOT conditions.

Air-Conditioning Relay

The A/C relay is what actually turns the compressor clutch on and off (Figure 10–33). When

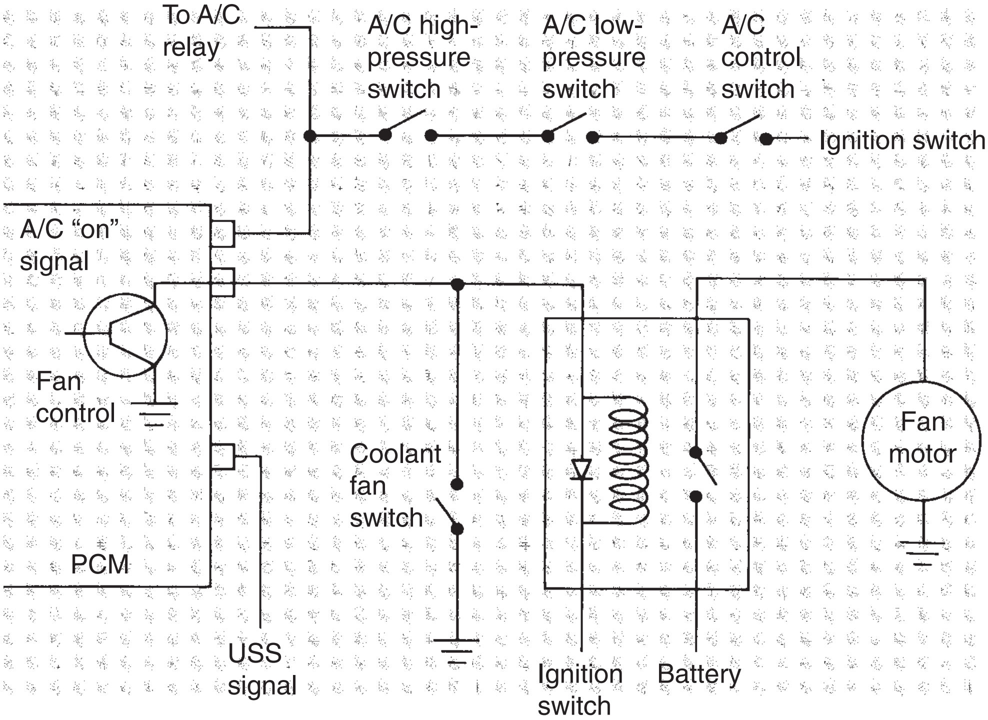


Figure 10–32 Cooling fan control circuit (typical).

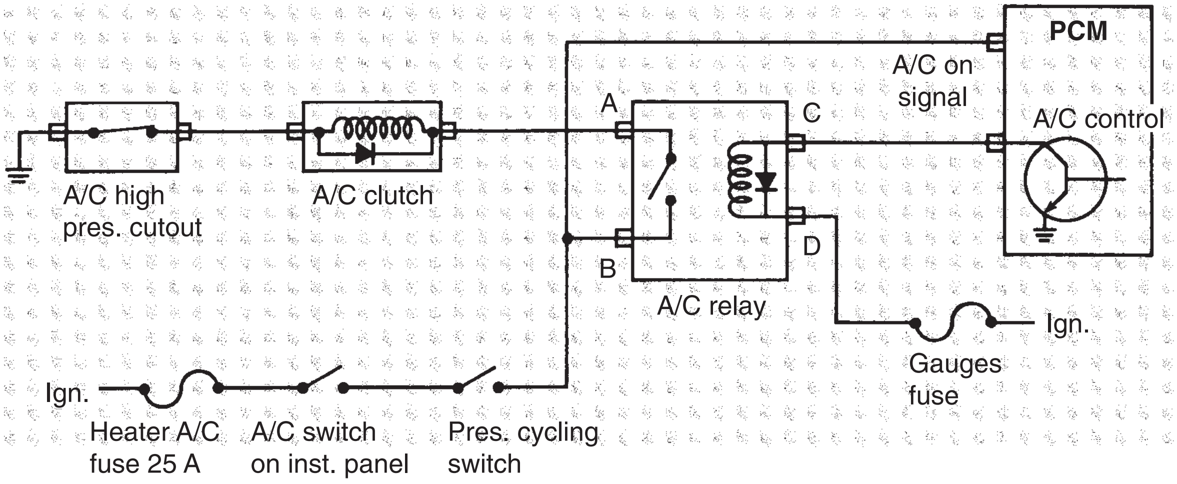


Figure 10–33 A/C relay circuit (typical).

the driver turns on the A/C switch, a signal goes to the PCM. The PCM waits a half second and then grounds terminal C of the relay. This energizes the relay and engages the compressor clutch (if the engine is at idle, the half-second delay allows the PCM time to adjust the IAC position and the engine idle speed before the compressor clutch engages). The PCM deactivates the relay at WOT, during heavy engine load, or when the IAC is in power-steering anti-stall mode. As shown in Figure 10–33, the compressor clutch circuit can also be opened by the high-pressure switch or the pressure cycling switch, both of which are standard features of the A/C system.

Related Emission Controls

On all but the Crossfire EFI system, EGR, canister purge, and air management are not controlled by the PCM. The EGR, canister purge, and air management controls on the Crossfire system are essentially the same as those on engines with PCM control, which is discussed in Chapter 11.

Catalytic Converter. Most EFI engine systems use single-bed, three-way catalytic converters. No supplemental air is introduced into the converter, so no air injection is used. In some cases a pulse air system is used, working independently of the computer.

Early Fuel Evaporation. Early fuel evaporation (EFE) systems have been used on engines in which both air and fuel travel through the intake manifold to reduce fuel condensation (puddling) during cold engine warm-up. If the fuel condenses on the intake manifold floor, it remains unused during normal driving, thus causing the engine to require more fuel. Then, during deceleration, when intake pressure is low (vacuum is high), this fuel vaporizes and creates an overly rich condition. To reduce this effect, two types of EFE systems have been used on GM vehicles with carburetors, feedback carburetors, and TBI systems. (As a rule, these EFE systems are eliminated on PFI systems.) One is an exhaust heat system used on V-engines that closes a valve when the engine is cold and forces exhaust gasses through a passage underneath the intake manifold floor to the opposite exhaust manifold. The other, used on in-line engines and some V-engines in front-wheel-drive applications, uses a ceramic heating grid underneath the throttle body.

The primary purpose of the EFE system is to apply heat to the area just below the throttle valves to prevent throttle blade icing and to increase fuel evaporation during the crucial engine warm-up period. This helps to:

- reduce the richness requirement of the air/fuel ratio
- improve driveability
- reduce hydrocarbon and carbon monoxide emissions

Rear-wheel-drive vehicles have used exhaust heat for this purpose, a system not under the control of the PCM. There is a valve in the exhaust pipe on one side of the engine where it bolts to the exhaust manifold. A vacuum actuator containing a spring and a diaphragm opens and closes this valve. A thermal vacuum switch controls vacuum to the actuator diaphragm. When coolant temperature is below 120°F (49°C), the thermal vacuum switch routes vacuum to the EFE actuator. This pulls the diaphragm against the spring and closes the EFE valve, forcing exhaust gasses from that side of the engine through a passage in the head and through the intake manifold EFE passage. The exhaust crosses beneath the plenum to the other head, where it travels through another passage to the exhaust pipe on that side. Once the coolant temperature rises above 120°F, a temperature-actuated vacuum control valve blocks vacuum to the actuator. The spring pushes the diaphragm back down and opens the EFE valve. Exhaust gas is no longer forced through the EFE passage.

The layout of front-wheel-drive cars makes this arrangement unsatisfactory, so they employ a ceramic-covered electric heat grid under the TBI unit as a source of EFE heat (Figure 10–34). A similar heat grid is also used on in-line engines. The heat grid is powered through a relay (the EFE relay), which is controlled by the PCM. The PCM activates the relay when all of the following conditions exist:

- Intake air temperature (IAT signal) is lower than 167°F (75°C).
- ECT signal is below 223°F (106°C).
- Battery voltage is above 10 V (in conditions of undercharge, the heating element could easily rob more important components using electric power).

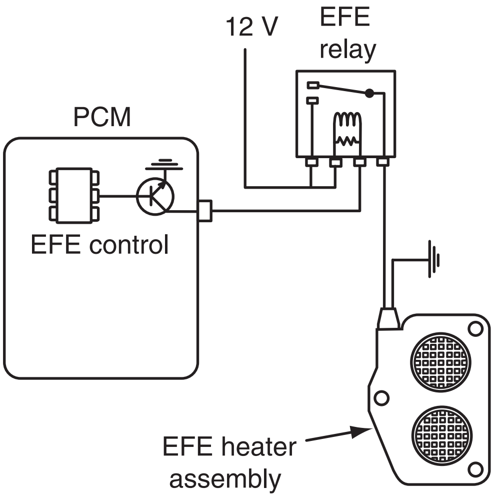


Figure 10–34 EFE grid.

If any one of these conditions is not met, the PCM turns the EFE relay off.

If the EFE has been turned off during the course of driving, the PCM will turn it back on if all of these conditions are met:

- IAT is below 100°F (38°C).
- ECT indicates below 223°F (106°C).
- Battery voltage is above 12 V.

Once any of the preceding conditions is no longer met, the PCM turns off the EFE relay.

One other set of conditions causes the PCM to turn on EFE heat. If throttle position is open more than 30 degrees (0 degrees is closed and 90 degrees is WOT) and IAT is less than 140°F (60°C), the PCM will turn on the EFE relay for at least 15 seconds to prevent throttle blade icing.

Exhaust Gas Recirculation. When the EGR valve opens, it allows a measured amount of exhaust gas (mostly nitrogen and carbon dioxide, neither of them capable of sustaining flame) into the intake manifold. This inert gas displaces a certain amount of ambient air and oxygen and the PCM also reduces the fuel proportionately. This has the effect of slowing the **propagation** of the flame through the combustion chamber. This slower flame burns at a lower temperature and thus reduces the production of oxides of nitrogen (NO_x).

Many EFI systems use a self-modulating backpressure EGR valve, controlled only by a ported vacuum signal and exhaust backpressure, using no PCM control.

Positive Backpressure EGR Valve. In a positive backpressure EGR valve, a second diaphragm is found under the primary diaphragm. A small spring pushes downward on the second diaphragm. A passage in the EGR valve stem allows exhaust manifold pressure to enter a chamber under the second diaphragm. When exhaust pressure is low, the small spring can hold the second diaphragm down in spite of the exhaust pressure pushing it up. Atmospheric pressure flows through a vent in the lower part of the EGR valve housing and through a port in the second diaphragm, into the space between the two diaphragms. If the second diaphragm is down, the atmospheric pressure can flow through another port in the main diaphragm into the vacuum chamber. With atmospheric pressure finding its way into the vacuum chamber, not enough vacuum is developed to lift the main diaphragm and open the EGR valve. As the throttle opening increases, exhaust manifold pressure increases. When exhaust pressure is high enough, the second diaphragm is forced up and closes off the port through the main diaphragm into the vacuum chamber. The vacuum chamber is no longer vented to atmospheric pressure, and sufficient vacuum can then develop to open the EGR valve.

Negative Backpressure EGR Valve. The Cadillac DFI system uses a negative backpressure EGR valve (Figure 10–35). This type of valve has some self-modulation capacity. Exhaust pressure from the exhaust crossover passage in the intake manifold (see EFE, covered earlier in this chapter) is sensed through a small hole in the lower portion of the valve itself. The hollow valve stem allows exhaust backpressure to get to a chamber beneath a second diaphragm below the main diaphragm. This pressure helps a small spring push the lower (second) diaphragm up and block a bleed hole in the main diaphragm. When the bleed hole is blocked, ambient air vented into the space between the two diaphragms no longer bleeds into the vacuum chamber above the main diaphragm. This allows the buildup of sufficient vacuum in the chamber (using manifold vacuum as the source) to pull the diaphragm up and open the EGR valve. When the valve opens, the same hole that admitted exhaust pressure also admits manifold vacuum.

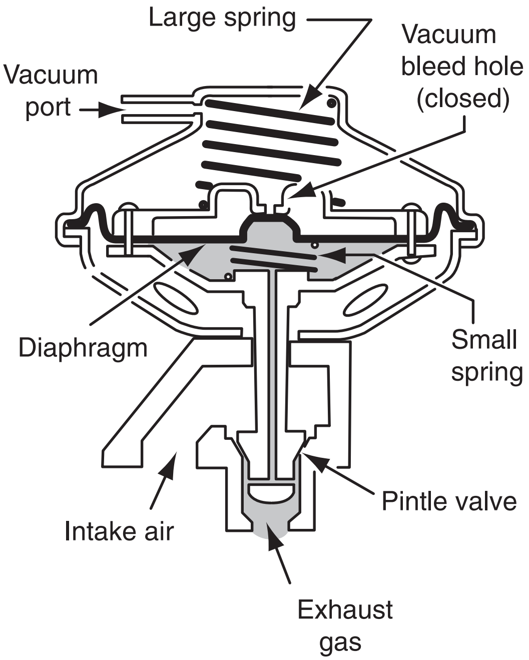


Figure 10–35 Negative backpressure EGR valve.

If the net result of the engine vacuum versus exhaust backpressure is a positive or near positive pressure, the lower diaphragm pushes up and opens the valve. If, however, the net result is a negative pressure, the lower diaphragm stays down and the bleed valve opens. This keeps the EGR valve itself closed.

EGR Modulation. In addition to the EGR control provided mechanically by the negative backpressure EGR valve, the Cadillac DFI system on the 4.1-L engine also controls vacuum to the EGR vacuum port. It does this with a

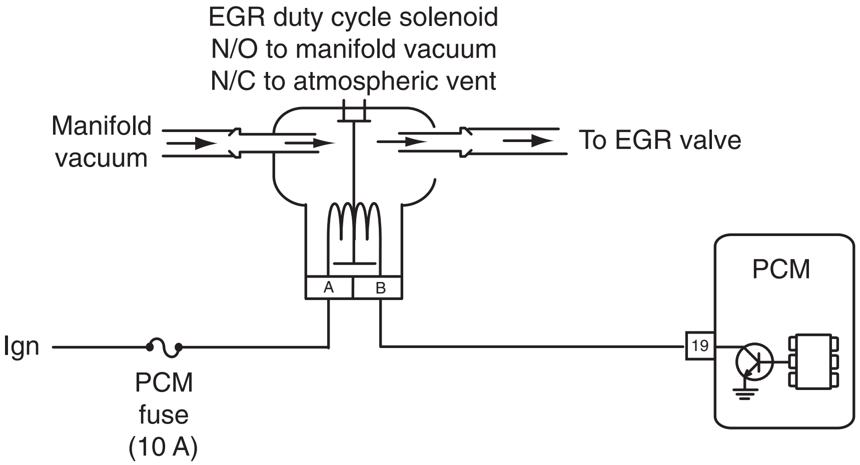


Figure 10–36 Duty-cycle controlled EGR control solenoid.

duty-cycled solenoid that bleeds atmospheric pressure into the vacuum supply hose to the EGR valve when on, causing the valve to close (Figure 10–36). When the solenoid is turned off, it allows manifold vacuum to the EGR valve and causes it to open. By duty cycling the solenoid, the PCM can control the amount of EGR opening and thus the EGR flow rate. The PCM varies the flow rate for different driving conditions to provide the best possible driveability characteristics while still maintaining control of the production of NO_x. A 10 percent duty cycle provides full vacuum to the EGR and a 90 percent duty cycle vents all vacuum to it, effectively closing the valve. The PCM uses information from the following sensors to determine the prevailing driving conditions and the amount of EGR needed:

- ECT signal—no EGR when coolant temperature is low because there would be no NO_x production at those temperatures anyway
- throttle position sensor (TPS) signal
- manifold pressure (MAP) signal
- idle control throttle switch (ISC signal—no EGR flow is needed at idle because combustion temperatures are not high enough to generate NO_x)
- ignition reference signal (REF)

Charcoal Canister Purge. Like other engine management systems, the C3 and DFI systems use an evaporative emissions control system consisting primarily of a charcoal canister that is plumbed to the vapor area of the fuel tank. The tank vents through the canister, and fuel vapors are stored in the activated charcoal in the canister.

On four-cylinder C3 EFI engines, canister purge control is achieved with a thermal vacuum switch, which blocks purge vacuum until the engine is warm enough to go into closed loop. In closed loop, any additional fuel from the canister can be compensated for by varying the injection on-time, while still maintaining the stoichiometric ratio of 14.7 to 1 air to fuel.

On other C3 and DFI applications, once the engine is running in closed loop, the PCM can open the line to the intake manifold and allow vacuum to purge the fuel vapors in the canister. Because the PCM has no way to tell how much fuel, if any, is stored in the canister, it waits until the system is in closed loop to allow any canister purge to occur, so it can compensate for any extra fuel or air introduced by the canister.

Canister purging is controlled by a combination of two valves—a control valve and a vacuum solenoid. The control valve is a vacuum-operated valve that is spring-loaded normally closed. A normally open vacuum solenoid under the control of the PCM controls a vacuum trigger signal that, in turn, is applied to the control valve (Figure 10–37).

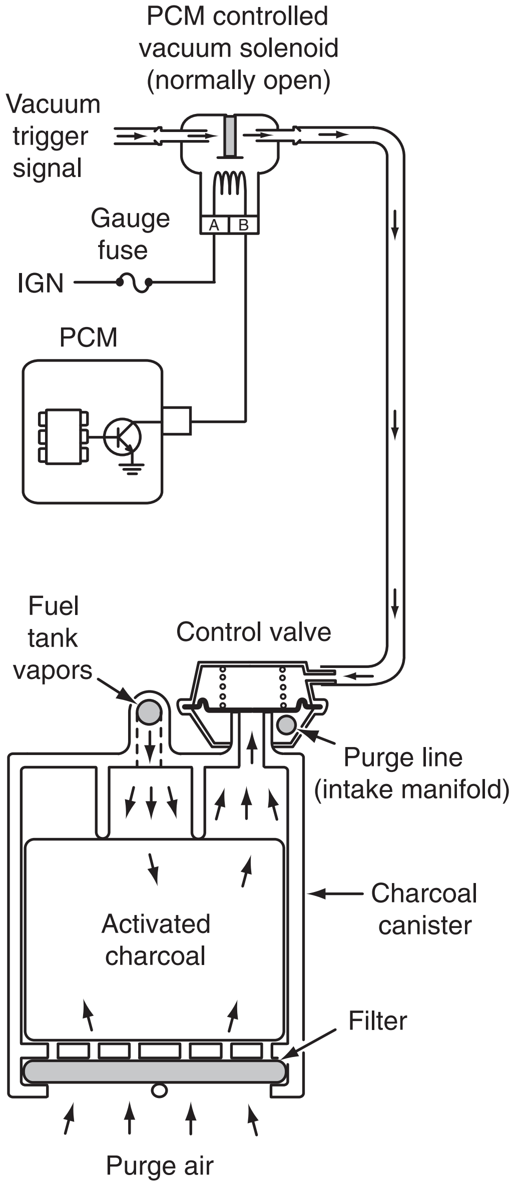


Figure 10–37 Charcoal canister, purge valve, and duty-cycle solenoid.

When a vacuum trigger signal is applied to the top of the diaphragm, it lifts and opens the passage to the purge port. By energizing and de-energizing the vacuum solenoid, the PCM is able to control the vacuum trigger signal to the control valve. When the vacuum solenoid is energized, the vacuum trigger signal to the control valve is blocked. The PCM de-energizes the vacuum solenoid to allow the vacuum trigger signal to open the control valve and therefore to allow purging when:

- the system is in closed loop and off idle
- no faults are present triggering codes 13, 16, 44, or 45

An electrical failure in the solenoid or its circuit allows purging to occur any time there is enough intake manifold vacuum. This can cause:

- an overly rich condition during warm-up or idle
- an overly lean condition during warm-up or idle (if the canister has no fuel vapors stored)
- dieseling after shutdown

Service Engine Soon Light

All GM C3 and DFI systems use a malfunction indicator light (MIL). Prior to OBD II standardization, this was sometimes called a "check engine light" or a "service engine soon light." If the PCM discovers a fault in one of the circuits it monitors for malfunctions, it turns on the MIL on the instrument panel. This warns the driver that a malfunction exists. On the C3 system, the MIL can also be used by a technician pulling *flash codes* from the PCM.

BODY CONTROL MODULE

The body control module (BCM) was first introduced on the 1985 C-body Cadillac and has been used on Cadillac DFI systems ever since. The BCM, like the PCM, is a microcomputer with all the basic components of the engine computer

(ROM, RAM, PROM, input/output interface) and about the same calculating power as the PCM. However, the BCM controls different functions on the vehicle than the PCM does. Following is a list of functions under the BCM's control:

- controls the electronic climate control (A/C system)
- controls the electric cooling fans drawing air through the A/C condenser and radiator
- controls the power windows, trunk release, and electric sunroof
- provides and displays information for the driver
- controls the information display panel dimming for visual clarity in different driving conditions
- monitors the BCM system for faults, storing codes to identify the faults and, in some cases, provides fail-safe measures to compensate for a system failure

The BCM and the PCM interact with each other. Information is exchanged between these two modules over a data bus. Figure 10–38 shows the kind of information the two computers exchange.

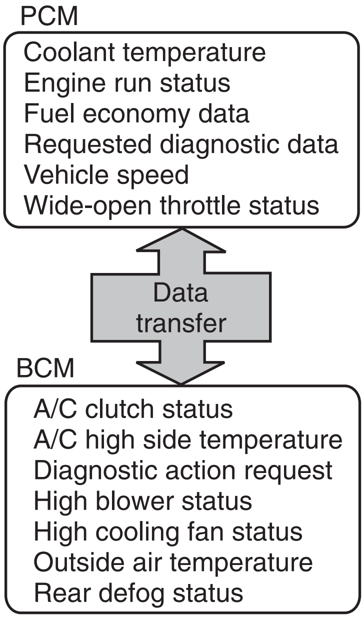


Figure 10–38 BCM/PCM interaction.

BCM-Controlled Electric Cooling Fans

Inputs. The BCM receives inputs for cooling fan operation from two sources: from the A/C high-pressure-side thermistor, located in the condenser outlet, and from the ECT information provided by the PCM.

Outputs. The speed of the two cooling fans is controlled by a PWM voltage signal produced by the BCM and sent to the fan control module (Figure 10–39). The module completes or opens the ground side of the fan's power circuit in response to the BCM signal. The PWM signal is cycled once every 0.032 second. If the signal voltage is high during only a short portion of the on-time, the fan motors run at low speed (Figure 10–40). This is because their power is supplied in short pulses and they spend most of each revolution coasting, though the momentum of the blades keeps their speed near constant. The greater the proportion of each period during which the pulsed on-voltage is high, the faster the fan motors turn.

The fans run at 40 percent of full speed when either the coolant temperature reaches 223°F (106°C) or the A/C high-pressure refrigerant temperature reaches 142°F (61°C). The fans run at full speed when either the ECT reaches 241°F (116°C) or the A/C high-side refrigerant temperature reaches 162°F (72°C). They turn off completely when either the coolant temperature drops to 216°F (102°C) or the A/C high-side refrigerant temperature drops to 135°F (57°C). The lower turn-off temperatures prevent the fans from dithering on and off if one of the temperatures hovers near the enable value.

The feedback signal sent to the BCM from the fan control module enables the BCM to monitor fan motor realization of the commands it was sent. This signal is near 12 V when the fans are off and near 0 V when they are on. The BCM compares feedback voltage to the commands it sent previously; if they do not match, it sets a fault code in memory.

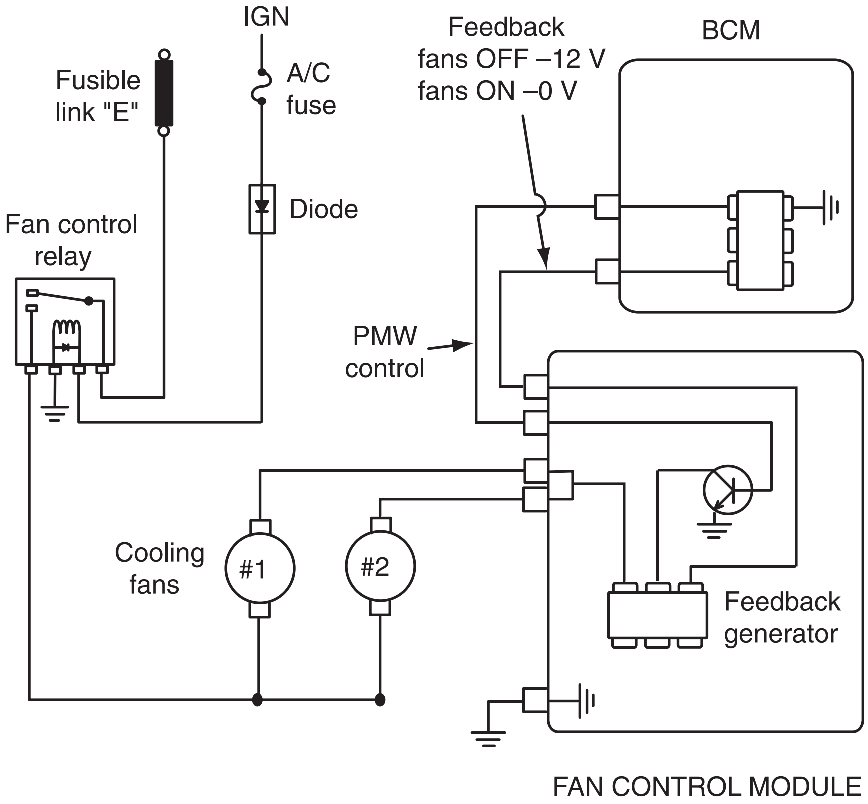


Figure 10–39 Cooling fan control.

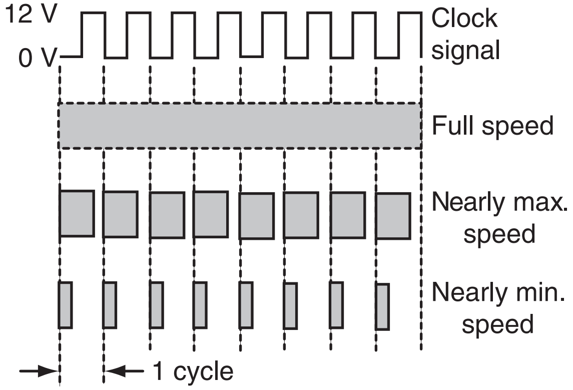


Figure 10–40 PWM command to cooling fan motors.

SYSTEM DIAGNOSIS AND SERVICE

Self-Diagnosis

The PCM monitors the major input sensors, the fuel pump, the EST system, and their respective circuits for proper operation. If the PCM sees a fault, such as an open, a short, or a voltage value that stays too high or too low for too long in any of the circuits it monitors, it turns on the MIL on the instrument panel and records a code number in its diagnostic memory. The code number identifies the circuit in which the fault exists. The MIL warns the driver that a fault exists. The MIL should come on, however, any time the ignition is on without the engine running, as a bulb check.

Diagnostic Memory. A portion of the PCM's random-access memory is devoted to diagnostic

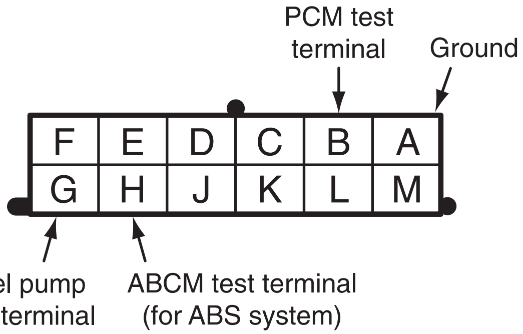


Figure 10–41 GM C3 DLC, 1982–1995.

memory, sometimes referred to as *long-term memory.* The diagnostic memory enables the PCM to store code numbers, referred to as *diagnostic trouble codes,* or DTCs (known by GM as "trouble codes" prior to OBD II), that identify the type of fault and the circuit in which the fault exists.

C3 System Diagnosis. A technician can obtain memory DTCs by either of two methods. Both methods use the DLC, which was known by GM prior to OBD II standardization as an *assembly line communications link* (ALCL) or *assembly line diagnostic link* (ALDL). Grounding the test terminal ("B") in the DLC to the ground terminal ("A") puts the system into diagnostics (Figure 10–41). (The DLC is most often located under the instrument panel, between the steering column and the radio.) The PCM pulses out its stored DTCs by flashing the MIL. All DTCs are stored as two-digit numbers. Two quick flashes followed by a pause of about 2 seconds represents a two; three more quick flashes represents the second digit, a three. Thus, the DTC would be a code 23 (Figure 10–42 demonstrates a code 12 being pulsed). Once the two-digit number completes, a slightly longer pause separates it from the next two-digit DTC. Once a DTC is displayed, it repeats twice more (for a total of three times) before moving on to the next code.

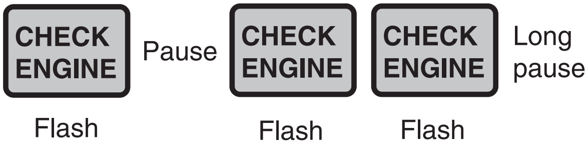


Figure 10–42 Check engine light in diagnostics.

The second method of obtaining stored DTCs is to connect a scan tool to the DLC and, with the ignition turned on, use it to pull the DTCs from the PCM's memory. The scan tool may also be used (with most C3 systems) to look at data stream information from the PCM, including input sensor values as interpreted *by* the PCM and output commands *from* the PCM.

DFI System Diagnosis. Like the C3 system, a scan tool may be connected to the 12-pin DLC (ALCL or ALDL) for diagnostic purposes. However, on this system, diagnostics may also be entered into without a scan tool through the following procedure:

- Turn the ignition switch to "run" or start the engine and let it idle.
- On the *electronic climate control panel* (ECCP), depress and hold the buttons marked "OFF" and "WARMER" simultaneously for about 5 seconds.
- Follow additional procedures as per the shop manual to pull codes and perform other functional tests of the system's components.
- Depending upon year and model, information may be displayed on the ECCP, the trip computer's display, or the instrument cluster.

Intermittent Faults. If the PCM sees a fault, it turns on the MIL and sets a DTC in memory. It keeps the MIL on until the ignition is turned off, or until the PCM no longer senses the fault. If the perceived fault clears up, the MIL goes off but the DTC remains in memory. If the fault does not repeat again within the next 50 ignition cycles (starting the engine and turning it off constitutes one ignition cycle), the DTC is automatically erased.

Clearing the Memory. The DTC can also be erased by disconnecting the power supply from the PCM for 10 seconds. This can be done most easily either by pulling the appropriate fuse (sometimes marked "PCM" and sometimes marked "clock") from the fuse panel, disconnecting the negative battery lead, or (on some later models) by disconnecting a fusible link near the positive battery terminal.

Approach to Diagnosis

When any of the diagnostic procedures are used, it is important to follow the directions carefully. Failing to do so or taking shortcuts usually results in inaccurate conclusions and leads to unneeded and ineffective repairs.

C3 System: Behavior in Diagnostics. When test terminal "B" in the DLC is grounded to terminal "A" and the engine is not running, the MIL should begin flashing code 12. Code 12 indicates no reference pulse is coming from the distributor, which is what you would expect since the engine is not running. Any additional stored codes display in numerical sequence after code 12.

Some other noteworthy points can be made about code 12. It is not a storable code (it is not stored in memory). It is most often used as an indication that the self-diagnostic function of the PCM is working properly. If you put the system into diagnostics with the engine off and do not see a code 12, the self-diagnostic function is not working and must be repaired before you can continue. The only time the presence of code 12 indicates a fault is if it displays when the engine is running, in which case it means the REF pulse is not coming in from the distributor to the PCM. (Obviously, in this scenario, while a feedback-carbureted engine might start and run, a fuel-injected engine would not run at all due to the lack of the tach reference pulse.)

All DTCs, beginning with code 12, will be seen a total of three times each. When the final DTC has flashed out on the MIL, the entire set of DTCs starts again, beginning with code 12. Therefore, the technician should recognize that when the fourth code 12 is seen, all DTCs have been displayed. If code 12 is displayed a fourth time without any other DTCs being flashed out, a "pass" is indicated. Code 12 does not mean "system pass." In fact, GM does not use a DTC to mean "system pass"; rather, a pass is indicated by the absence of fault codes between sets of code 12.

C3 System: Diagnostic Circuit Check. When diagnosing a problem on an EFI system, after verifying that all non-EFI engine support systems are working properly, start with a diagnostic circuit check (Figure 10–43). The diagnostic circuit check either verifies that the system is working properly or refers to another chart for further diagnosis. Be sure that the diagnostic circuit check and trouble code charts come from the same model-year manual as the vehicle you are working on. While some techniques and codes are retained over several years and for various vehicles, others are changed with some frequency. On earlier systems, the diagnostic circuit check is designed to sort out whether the fault currently exists or if it is intermittent—present once but not now. On such systems, the trouble code charts are written assuming the fault exists currently. If one of these is used to pursue an intermittent code, the chart most often leads to an invalid diagnosis because it is beginning with an invalid assumption: that a fault currently exists when, in fact, none does.

For later systems, the diagnostic circuit check and many of the trouble code charts are written to allow the trouble code charts to determine whether the code obtained from the diagnostic memory identifies a current fault (a hard fault) or an intermittent fault.

C3 System: Field Service Mode. Grounding the test terminal with the engine running puts the system into field service mode. In this mode the PCM uses the check engine light to show whether the system is in open or closed loop and whether the system is running rich or lean. While in this mode, if the check engine light flashes at a rate of two times per second, the system is in open loop. If it flashes at a rate of one time per second, the system is in closed loop. If the light is turned *off* most or all of the time, the system is in closed loop and a lean exhaust condition is indicated (O_2 sensor stays *below* 450 mV most or all of the time). If the light is turned *on* most or all of the time, the system is in closed loop and a rich exhaust condition is indicated (O_2 sensor stays *above* 450 mV most or all of the time).

The field service mode was incorporated into the diagnostic circuit check in 1984 but was discontinued when the diagnostic procedures were written around the use of a scanner. The scan tool provides the information the field service mode was designed to provide.

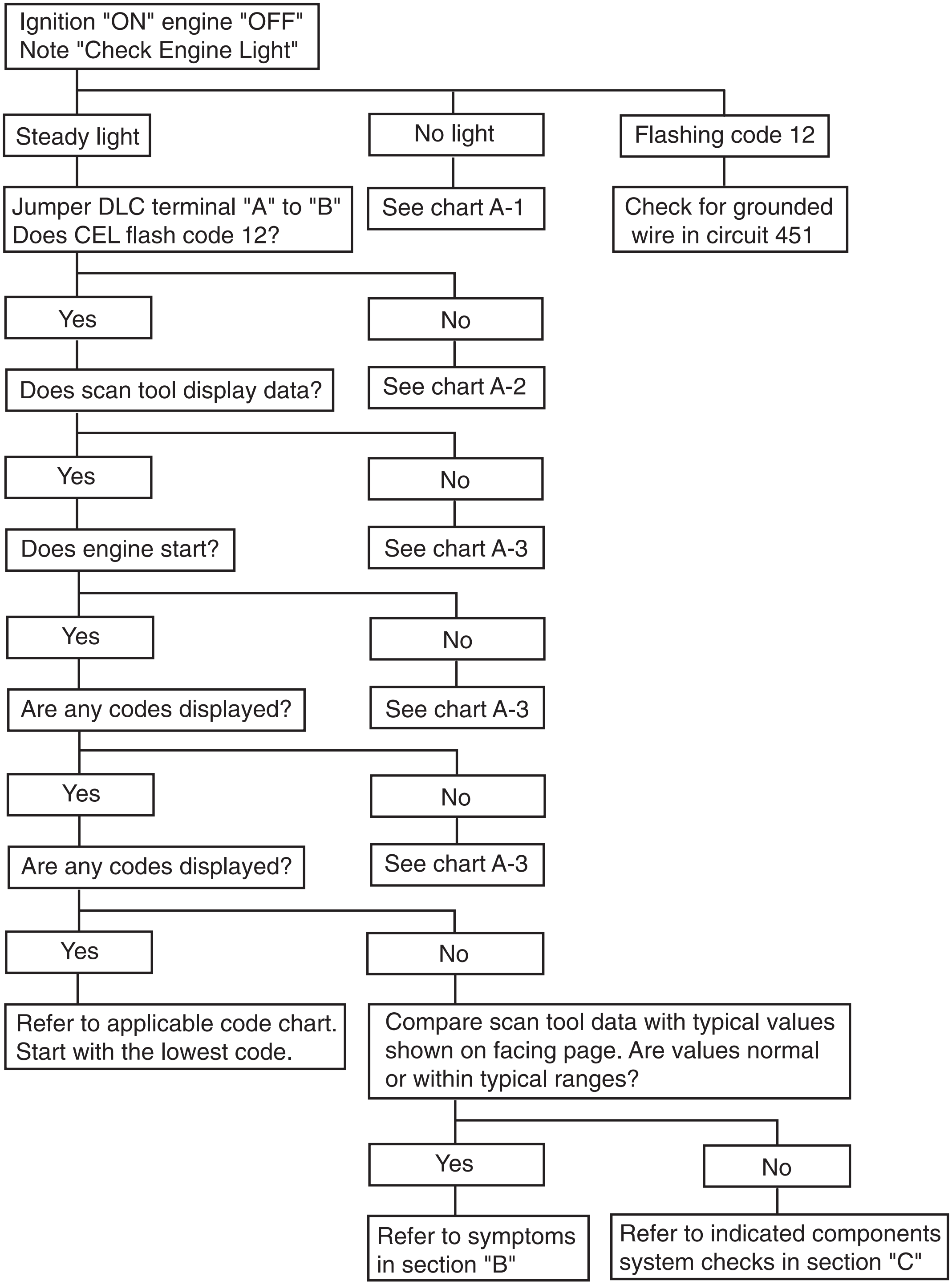

Ignition "ON" engine "OFF"
Note "Check Engine Light"
Steady light
No light
Flashing code 12
Jumper DLC terminal "A" to "B"
Does CEL flash code 12?
See chart A-1
Check for grounded wire in circuit 451
Yes
No
Does scan tool display data?
See chart A-2
Yes
No
Does engine start?
See chart A-3
Yes
No
Are any codes displayed?
See chart A-3
Yes
No
Are any codes displayed?
See chart A-3
Yes
No
Refer to applicable code chart. Start with the lowest code.
Compare scan tool data with typical values shown on facing page. Are values normal or within typical ranges?
Yes
No
Refer to symptoms in section "B"
Refer to indicated components system checks in section "C"

Figure 10–43 Diagnostic circuit check.

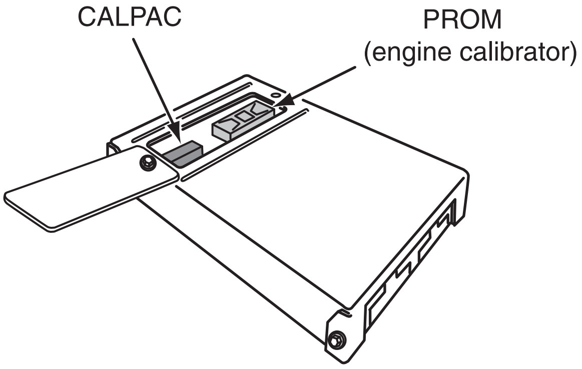


Figure 10–44 PROM and CALPAK in PCM.

PCM and PROM Service

Considerable care should be taken when working on a PROM or CALPAK (used only on 2.0-L engine PCMs). A finger touching one of the pins can discharge enough static electricity into it to damage its memory data (Figure 10–44). The PROM carrier fits into the PROM cavity of the PCM in only one position. The PROM, however, fits into the carrier in either of two ways (Figure 10–45). If the PROM is installed in the PCM in the incorrect orientation (reversed 180 degrees), it will be damaged electrically and may also damage the computer. Consult the service manual for detailed installation instructions.

The PROM, CALPAK, and PCM are serviced separately. Therefore, the technician should remove the PROM and CALPAK before exchanging the PCM for a new one. The same PCMs are used on a variety of vehicles; PROMs and CALPAKs are specific to each vehicle model, year, and accessory package. If the CALPAK or PROM is missing or damaged, the engine may not start.

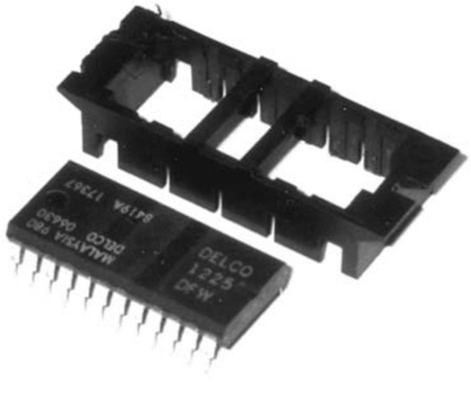


Figure 10–45 PROM IC chip and carrier.

Weather-Pack Connectors

All CCC system harness connections under the hood are made with weather-pack connectors (Figure 10–46) designed to provide environmental protection for sensitive electrical connections so that corrosion and contamination buildup are

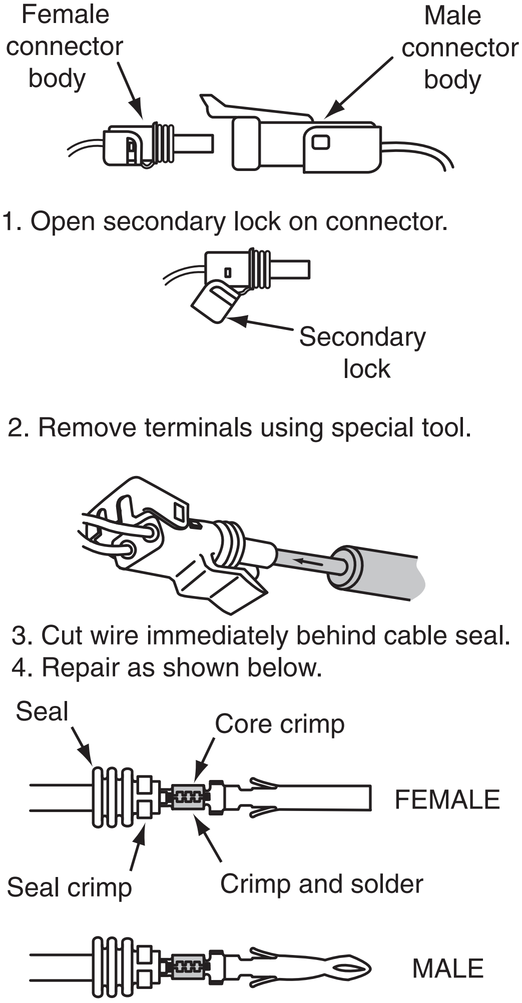
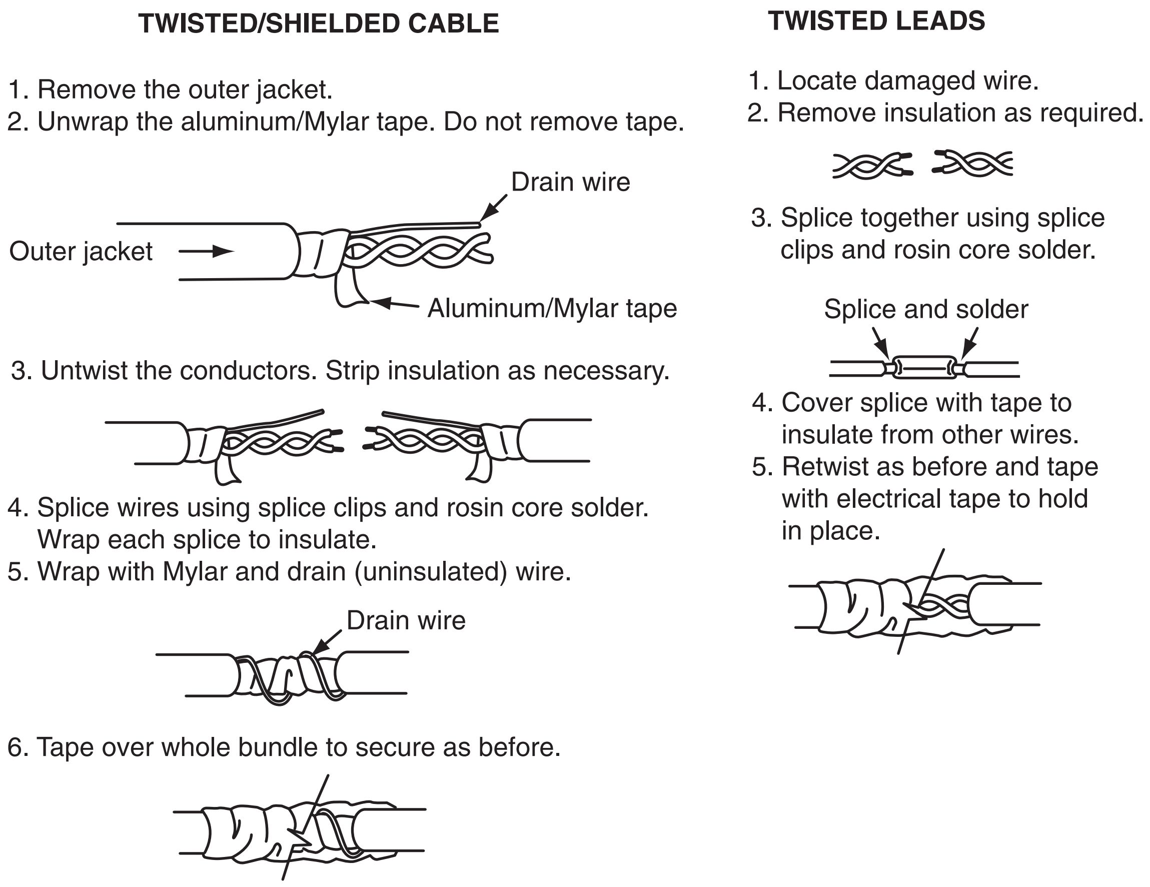

Female connector body
Male connector body
1. Open secondary lock on connector.
Secondary lock
2. Remove terminals using special tool.
3. Cut wire immediately behind cable seal.
4. Repair as shown below.
Seal
Core crimp
FEMALE
Seal crimp
Crimp and solder
MALE

Figure 10–46 Weather-pack connector.



TWISTED/SHIELDED CABLE

1. Remove the outer jacket.
2. Unwrap the aluminum/Mylar tape. Do not remove tape.
3. Untwist the conductors. Strip insulation as necessary.
4. Splice wires using splice clips and rosin core solder. Wrap each splice to insulate.
5. Wrap with Mylar and drain (uninsulated) wire.
6. Tape over whole bundle to secure as before.

TWISTED LEADS

1. Locate damaged wire.
2. Remove insulation as required.
3. Splice together using splice clips and rosin core solder.
4. Cover splice with tape to insulate from other wires.
5. Retwist as before and tape with electrical tape to hold in place.

Figure 10—47 Wire repair.

held to a minimum. Many of the circuits in the CCC system do not carry more than 1 or 2 milliamps at about 100 mV (0.1 V). Any resistance caused by oxidation or contamination of an electrical connection can have a significant impact on the performance of the system. It is important that the integrity of the weather-pack connectors be maintained. Do not break the seal by inserting a probe into the connector. Voltage readings can be obtained by opening the connector and temporarily installing short jumper wires made for this purpose (many voltage checks require that the circuit be electrically connected during the test). If the weather-pack connector has been damaged, replace it as shown in Figure 10–46 or solder and tape the connection as shown in Figure 10–47.

Surging Complaints. Surging complaints are occasionally heard concerning C3 and DFI vehicles at steady-state speeds around 35 MPH or higher. This is a fairly common problem, often caused by the EGR valve, and is sometimes referred to as *EGR chuggle.* The inert gasses introduced in the intake manifold by the EGR valve can cause an increased frequency of cylinder misfires. Although this has been occurring since the EGR valve's introduction in the early 1970s, it was not noticeable to the driver until the TCC was added to the torque converter, making it a solid coupling. In combination with lower axle numerical ratios, this has caused the surging to become more perceptible. This complaint is sometimes misdiagnosed as a malfunction of the lockup torque converter. To isolate the problem, temporarily disconnect and plug the vacuum line from the EGR valve. Test drive to see whether the surging still occurs. If it does, the problem is not EGR related.

Diagnostic & Service Tip

The **TPS** is the one sensor that can be adjusted. Sometimes driveability complaints can be cured by adjusting the TPS to exact specifications, which often vary with engine and model-year application. Be sure to check the applicable service manual for correct procedures and specifications.

Diagnostic & Service Tip

When using the TCC test terminal in the DLC, remember the following points (use a service manual to identify the TCC test terminal):

- Voltage is present when the TCC is not applied and is near zero when the TCC is applied because applying the TCC causes the voltage to drop across the apply solenoid.
- The TCC can be applied by grounding the TCC test terminal.
- Applying voltage to the TCC test terminal damages the PCM if the PCM tries to apply the TCC while the voltage is applied.

CAUTION: Do not leave the EGR valve disconnected. To do so is not only emissions tampering and against the law, it can also result in engine damage from detonation.

Vacuum Leaks. A vacuum leak on an EFI system usually results in increased idle speed while in closed loop.

TBI Injector O-rings. The TBI unit has two O-rings between the injector solenoid and the fuel metering body. The O-rings prevent pressurized fuel from leaking past the injector solenoid. A leak at either of these O-rings can result in dieseling and/or an overly rich mixture. A suspected leak can be checked easily. With the engine off and a jumper lead supplying battery voltage to the fuel pump test terminal, inspect the injector for signs of leaks.

WARNING: Fuel Pressure Test. Some driveability complaints require a fuel pump pressure test. Before the fuel system is opened, pressure in the line should be relieved. The system is designed to retain operating pressure in the line after the engine is shut off. Opening the line under pressure causes a considerable spray of fuel, resulting in a fire and personal safety hazard. To relieve the pressure, remove the fuel pump fuse and crank the engine for several seconds. See the service manual for further test procedures.

Erasing Learned Ability. Any time battery power is removed from the PCM, its learned memory is lost. This can produce a noticeable change in performance. Learning can be restored by driving the car, usually for not more than half an hour at normal operating temperature, part throttle and idle, and at moderate acceleration.

SUMMARY

We have covered the most important information inputs the computer uses to calibrate the engine's delivered fuel mixture and spark advance—factors such as engine and air temperatures, engine speed and load, throttle position, and vehicle speed. The various ways these sensors work and what use the computer makes of each kind of signal were reviewed. We have learned how fuel pump and ignition circuits work in the system, as well as other outputs and systems that are controlled by the PCM.

We also took a quick look at the introduction of another computer in the DFI system known as the BCM and saw how it interacts with the PCM to control other systems as well. And we saw the diagnostic procedures and precautions associated with the C3 and DFI systems that are used to control General Motors TBI systems.

▲ DIAGNOSTIC EXERCISE

A vehicle is brought in with surging and other driveability complaints. When put into diagnostic mode, the computer displays DTCs pointing to the TPS circuit. Describe the steps a technician should follow between finding that DTC and deciding to replace the TPS.

Review Questions

1. What does the PCM do in synchronized mode?
    A. Pulses both TBI fuel injectors simultaneously.
    B. Pulses the TBI fuel injector(s) once for each tach reference signal from the distributor.
    C. Pulses the TBI fuel injector(s) once for each pulse from the VSS.
    D. Pulses the TBI fuel injector(s) every 12.5 ms.
2. Technician A says that during cranking mode, if the throttle is opened less than 80 percent, the PCM determines the proper fuel injector pulse width from the ECT sensor. Technician B says that during cranking mode, if the throttle is opened wider than 80 percent, the PCM leans out the air/fuel ratio to about 20:1 to help the driver relieve a flooded condition. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
3. Technician A says that if the ground-side wire of the TPS open-circuited, resulting in a 5-V signal to the PCM, this would cause the PCM to enter clear flood mode when the engine is cranking. Technician B says that if the ground-side wire of the TPS were to open-circuit, resulting in a 5-V signal to the PCM, the engine could be very difficult to start under normal conditions when it is not flooded. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
4. What other function does the MAP sensor serve beyond informing the PCM of manifold absolute pressure?
    A. It informs the PCM of intake air temperature.
    B. It informs the PCM of the atmosphere's relative humidity.
    C. It informs the PCM of barometric pressure.
    D. It serves no other function.
5. Which of the following inputs affect(s) the PCM's control of the engine's idle speed?
    A. Park/neutral (P/N) switch
    B. Air-conditioning (A/C) switch
    C. Fuel pump voltage signal
    D. Both A and B
6. Technician A says that the fuel pressure regulator on a C3 system is used to maintain fuel pressure at the fuel injector(s) within a range of 9 to 13 PSI. Technician B says that the spring side of the fuel pressure regulator's diaphragm is exposed to atmospheric pressure to allow slight fuel pressure adjustments to maintain a consistent pressure differential across the injector(s) regardless of altitude or weather conditions. This results in a consistent flow rate any time an injector is energized. Who is correct?
    A. Technician A only
    B. Technician B only

   C. Both technicians
   D. Neither technician

7. The idle air control (IAC) assembly used by the PCM to control idle speed is which of the following?
   A. Vacuum-operated diaphragm
   B. Reversible DC motor
   C. Stepper motor
   D. Duty-cycle solenoid
8. What type of device is used by the PCM to energize the fuel pump, the cooling fan, and the A/C clutch?
   A. Solenoid
   B. Diode
   C. Potentiometer
   D. Relay
9. What function(s) does the fuel pump test terminal serve?
   A. It allows a technician to use a jumper wire to manually power the fuel pump motor.
   B. It allows a technician to use a voltmeter to see if the fuel pump relay or oil pressure switch is providing power to the fuel pump motor.
   C. It allows a technician to test the resistance of the fuel pump relay winding.
   D. Both A and B
10. What are the first two steps when pursuing a driveability complaint on an EFI-equipped vehicle?
   A. Replace the ignition module, then scope the primary ignition system to be sure that a tach reference signal is present.
   B. Replace the PCM, then test the fuse labeled "PCM."
   C. Replace the oxygen sensor, then replace the EGR valve.
   D. Verify that all non-EFI engine support systems are working properly, then perform a diagnostic circuit check.
11. A vehicle equipped with EFI is brought into the shop with a complaint of poor fuel mileage and is also emitting black smoke out of the tailpipe during some driving conditions. A fuel pressure check shows that the fuel pressure is too high. What is the most likely cause?
   A. A defective fuel pump
   B. A defective fuel pressure regulator
   C. High resistance on the ground side of the fuel pump
   D. A defective PCM
12. When the engine is cranking, the EST system operates the switching transistor according to the pickup coil signal (base timing). What mode is this known as?
   A. Module mode
   B. Bypass mode
   C. EST mode
   D. HEI mode
13. Once the engine is running, the PCM begins to control the switching transistor in the EST system (computed timing). What mode is this known as?
   A. Module mode
   B. Bypass mode
   C. EST mode
   D. HEI mode
14. When determining computed timing on an EFI system, the PCM considers all of the following inputs *except* which of the following?
   A. Barometric and manifold pressure
   B. Engine coolant temperature
   C. Engine oil pressure
   D. Crankshaft position and RPM
15. What is the purpose of the ESC system?
   A. To determine how far computed timing should be advanced
   B. To retard ignition timing when detonation occurs
   C. To alert the PCM to a cylinder that is misfiring
   D. To sense how much spark advance is being added in by the vacuum and centrifugal advance mechanisms
16. On most EFI vehicles, the PCM will turn on the electric cooling fan when the A/C is turned on and vehicle speed drops below which of the following?
   A. 20 mph
   B. 30 mph
   C. 40 mph
   D. 50 mph

17. Most EFI applications use which of the following?
    - A. Single-bed, two-way catalytic converter with no air injection into the converter
    - B. Single-bed, three-way catalytic converter with no air injection into the converter
    - C. Dual-bed, three-way catalytic converter with no air injection into the converter
    - D. Dual-bed, three-way catalytic converter with an air injection system
18. Technician A says that a GM EFI system uses weather-pack connectors at all computer system connections in the engine compartment. Technician B says that a vacuum leak on an EFI application can result in an idle speed that is too fast. Who is correct?
    - A. Technician A only
    - B. Technician B only
    - C. Both technicians
    - D. Neither technician
19. When replacing the PCM on an EFI application, what component(s) should be transferred from the old PCM to the new PCM?
    - A. RAM
    - B. PROM
    - C. CALPAK
    - D. Both B and C
20. Technician A says that any time battery power has been disconnected from the PCM, the learned memory can be lost, resulting in a noticeable change in engine performance. Technician B says that it is a good idea to road test the vehicle after the battery has been disconnected to begin the PCM's relearning process before returning the vehicle to the customer. Who is correct?
    - A. Technician A only
    - B. Technician B only
    - C. Both technicians
    - D. Neither technician

Chapter 11

General Motors and Port Fuel Injection

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Define the operating modes of a GM PFI system.
- ☐ Define the inputs associated with a GM PFI system.
- ☐ Describe the operation of a GM PFI fuel system.
- ☐ Describe the operation of the idle speed control system associated with a GM PFI system.
- ☐ Describe the operation of the spark management systems associated with a GM PFI system.
- ☐ Understand the emissions control systems associated with a GM PFI system.
- ☐ Explain the operation of a turbocharger and the turbocharger wastegate.

KEY TERMS

AC
Block Learn
Central Multiport Fuel Injection (CMFI)
Central Sequential Fuel Injection (CSFI)
Computer Controlled Coil Ignition (C3I)
Fuel Trim
High-Pressure Cutout Switch
Integrator
Longitudinal
Normally Aspirated
Pressure Cycling Switch
Pulsair System
Thermac
Thermo-Time Switch
Vehicle Control Module (VCM)
Wastegate

Excluding the Cadillac Digital Fuel Injection system, Port Fuel Injection (PFI) represents the fourth generation of comprehensive computerized engine control systems of General Motors. The PFI system was introduced in limited applications on 1984 models as the port fuel injected version of the Computer Command Control (CCC or C3) system. It follows the first closed-loop fuel control system introduced in 1978, the feedback-carbureted version of the C3 system introduced in 1980, and the EFI (TBI) version of the C3 system introduced in 1982. In 1985 the PFI system was expanded to several engine applications. Some General Motors car divisions have chosen special names for the system because of some special features designated for particular engine or body applications. These special features include:

- sequential fuel injection (SFI) on the turbocharged 3.8-L engine.
- multiport fuel injection (MFI) on most other engines.
- tuned port injection (TPI) on the Corvette 5.7-L engine. The TPI version includes tuned intake manifold runners, matched in shape, length, and cross-sectional area to help maximize volumetric efficiency (VE).

Because only air moves through the intake manifold, there is no concern about holding fuel in a vapor state as it passes through the runners.

Consequently, the heated intake air **(Thermac)** and the early fuel evaporation (EFE) systems are eliminated. Most PFI applications do run engine coolant through a passage in the throttle body to prevent the formation of ice around the throttle blade.

POWERTRAIN CONTROL MODULE

The powertrain control module (PCM) is usually located under the instrument panel or behind the passenger kick panel. On the P car (Pontiac Fiero) it is in the console between the front seats. It contains a removable PROM and CALPAK. The CALPAK provides calibration for cold-start cranking and for fuel backup in the event of a PCM failure. The fuel backup circuit (FBC) provides an operating mode when any of the following conditions occur:

- PCM voltage falls below 9 V (most likely during cold cranking).
- The PROM is missing or not functioning.
- The PCM is unable to provide its normal computer-operated pulses.

The FBC makes use of the throttle position sensor (TPS), the coolant temperature sensor signal, and the engine RPM signal. It is powered through the ignition switch. During FBC mode, the engine runs erratically and sets a code 62.

Keep-Alive Memory

The PCM has essentially the same self-diagnostic capacity and keep-alive memory (KAM) as discussed in Chapter 10. The inputs fed into the PCM and the functions controlled for most systems are shown in Figure 11–1.

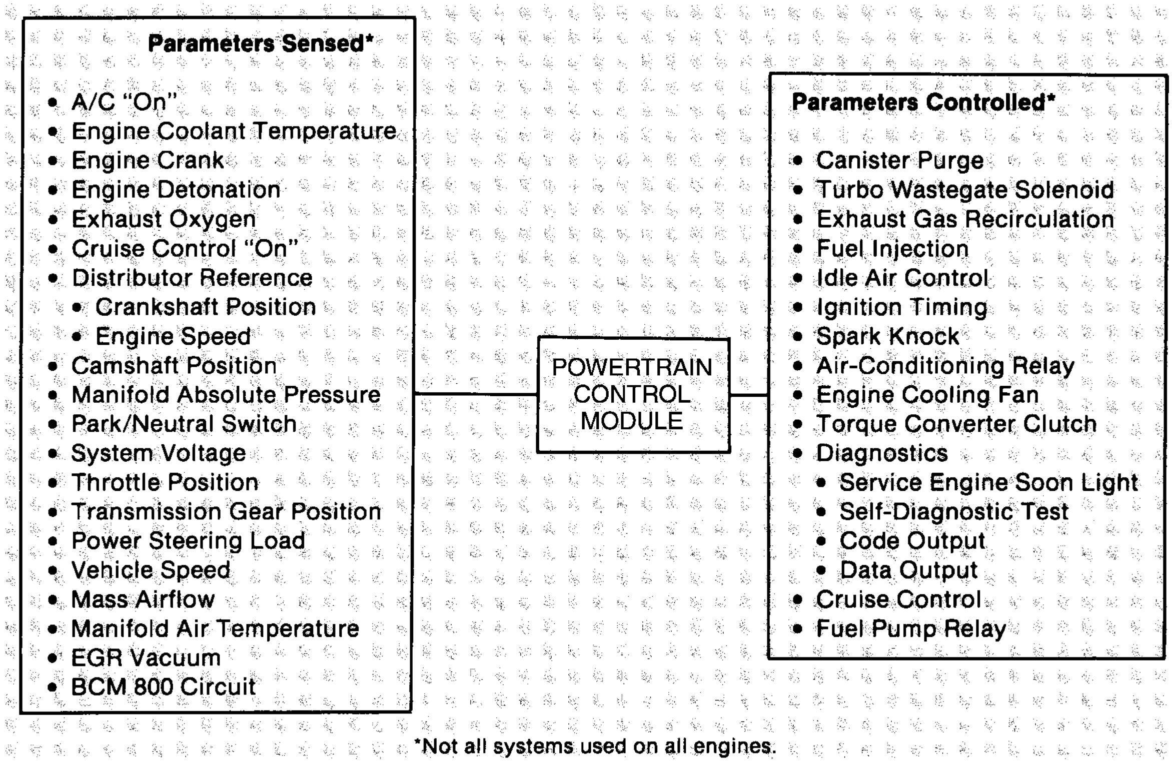


Figure 11–1 PFI system overview.

Vehicle Control Module

The familiar PCM on a General Motors application provides powertrain control—that is, it controls both engine performance (fuel, spark, and emissions systems) and electronic transmission performance. On some vehicles it also controls the cruise control (speed control) system. However, another name for the General Motors PCM can now be found in the service manuals: **vehicle control module (VCM).** In addition to controlling all of the features identified above, a VCM also controls the vehicle's antilock braking system (ABS) without having to incorporate a separate dedicated control module for this purpose. Therefore, GM vehicles may now utilize either a PCM or a VCM, depending upon whether the ABS system is under the control of the engine computer, and either term may be used to identify the engine computer on a GM vehicle.

OPERATING MODES

The different operating modes of the PFI system control how much fuel is introduced into the intake manifold for the various possible operating conditions.

Starting Mode

When the ignition is turned on, the PCM turns on the fuel pump relay. If it does not see an ignition signal within 2 seconds telling it that the engine is cranking, it turns the fuel pump off again. The fuel pump provides fuel pressure to the injectors. As the system goes into cranking mode, the PCM checks coolant temperature and throttle position to calculate what the air/fuel ratio should be for this startup. The air/fuel ratio ranges from maximally rich, 1.5 to 1, at –32°F (–36°C), to maximally lean, 14.7 to 1 at 201°F (94°C). The PCM varies the air/fuel ratio by controlling the time the injectors are turned on (referred to as the "pulse width").

The 2.8-, 5.0-, and 5.7-L engine PFI applications use a cold-start injector. This is an additional fuel injector in the intake manifold that improves cold starting by spraying additional fuel into the intake manifold during cranking. Spraying the additional fuel for cold-start enrichment into the manifold gives the fuel more opportunity to evaporate in the cold, dense air than if it were sprayed directly into the intake ports. The injector is not controlled by the PCM. Rather, it is activated by the cranking system and by a thermal time switch (described more fully in the "Outputs" section of this chapter).

Clear Flood Mode

The clear flood mode works essentially the same as it does on the EFI system. As long as the engine is turning below 600 RPM and the throttle is held to 80 percent WOT or more, the PCM will keep the air/fuel ratio at 20 to 1, except on the 2.8-L engine, which cuts off fuel completely in clear flood. The same troubleshooting considerations apply to this system's clear flood mode as to the system in Chapter 10.

Run Mode

The run mode consists of the open- and closed-loop operating conditions. When the engine starts and the RPM rises above 400, the system goes into open loop. In open loop, the PCM ignores information from the oxygen sensor and determines air/fuel ratio commands based on input from other sensors (coolant temperature, vacuum or mass air flow [MAF], and throttle position, as well as engine speed if the vacuum sensor is used). The system stays in open loop until:

- the oxygen sensor produces a varying voltage showing that it is hot enough to work properly
- the coolant is above a specified temperature
- a specified amount of time has elapsed since the engine last started

These values vary with engine application and are hardwired into the PROM. When all three conditions are met, the PCM puts the system into closed loop. In closed loop, the PCM uses oxygen sensor input to calculate air/fuel ratio commands and keeps the air/fuel ratio at a near-perfect 14.7 to 1. During heavy acceleration, wide-open throttle (WOT), or hard deceleration, the system temporarily drops out of closed loop.

Acceleration Mode

Rapid increases in throttle opening and manifold pressure or air flow signal the PCM to enrich the air/fuel mixture. This compensates for the reduced evaporation rate of the gasoline resulting from the higher manifold pressure.

Deceleration Mode

Rapid decreases in throttle opening and manifold pressure or air flow cause the PCM to lean the air/fuel mixture. If the changes are severe enough, fuel is momentarily cut off completely.

Battery (Charging System) Voltage Correction Mode

The battery voltage correction feature on the PFI system is different from that on the EFI system. On the PFI system, when battery voltage drops below a specified value, the PCM:

- enriches the air/fuel mixture according to a preset formula
- increases the throttle bypass air if the engine is idling
- increases ignition dwell to compensate for a weakened ignition spark should the coil's magnetic field not build sufficiently to generate a hot secondary spark

Fuel Cutoff Mode

When the ignition is turned off, the PCM immediately stops pulsing the injectors to prevent dieseling as well as to consume the fuel mixture remaining in the ports. Injection is also stopped any time the distributor reference pulse (REF) stops coming to the PCM.

FUEL SUPPLY SYSTEM

Fuel pressure is supplied by an electric pump in the fuel tank (Figure 11–2). The pump is turned on and off by a fuel pump relay controlled by the PCM. A pressure relief valve in the pump limits maximum pump pressure to between 80 and 90 psi. This pressure is realized only if flow stops and the pump is working against static pressure. The filter mounted to the bottom of the pump assembly is a 50-micron filter; downstream is another filter, a 10- to 20-micron in-line filter (1 micron is one-millionth of a meter). Because of the high operating pressure, an O-ring is used at all threaded connections, and all flex hoses have internal steel reinforcement.

Fuel pressure is controlled by the fuel pressure regulator (Figure 11–3), which is usually mounted on the fuel rail in the engine compartment (Figure 11–4). Manifold vacuum is supplied to the spring side of the diaphragm. At light throttle, the high vacuum helps pull the diaphragm up and against the spring. This allows more fuel to return to the tank, thus reducing output pressure. Pressure at the injectors ranges from 34 psi at idle to 44 psi at full throttle.

At idle, when pressure within the intake manifold is *low* (high vacuum), fuel rail pressure is also *low.* At WOT, when pressure within the intake manifold is *high* (low vacuum or no vacuum), fuel rail pressure is also *high.* If the intake manifold pressure is increased beyond atmospheric pressure through turbocharging, fuel rail pressure is also equally increased. Indexing the fuel rail pressure to a manifold vacuum (actually, manifold absolute pressure) signal allows the fuel pressure to vary equally with the pressure in the intake manifold. This keeps the pressure differential across the fuel injectors (between the inlet and outlet ends) constant under all engine operating conditions. Since the injector orifice size is fixed on a given engine, if the pressure differential is held constant, the flow

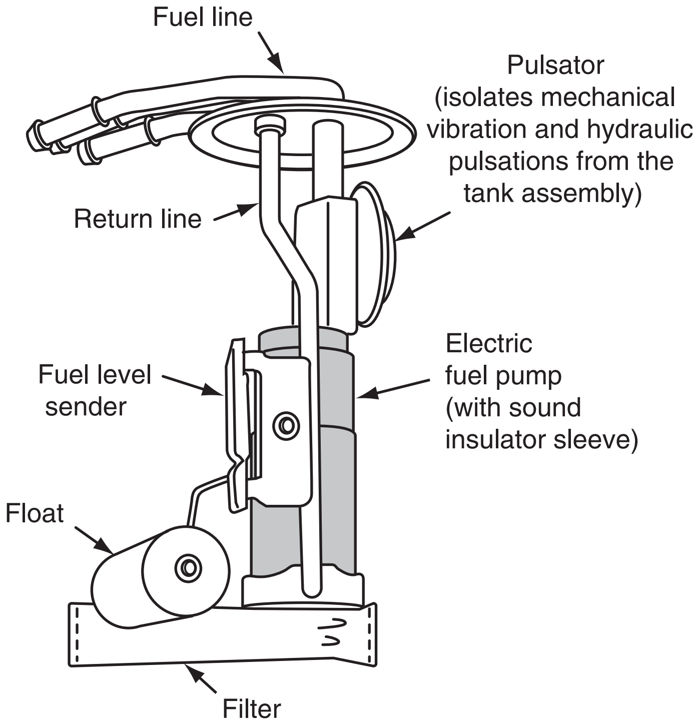

Fuel line
Pulsator
(isolates mechanical vibration and hydraulic pulsations from the tank assembly)
Return line
Electric fuel pump (with sound insulator sleeve)
Fuel level sender
Float
Filter

Figure 11–2 Fuel pump and sending unit assembly.

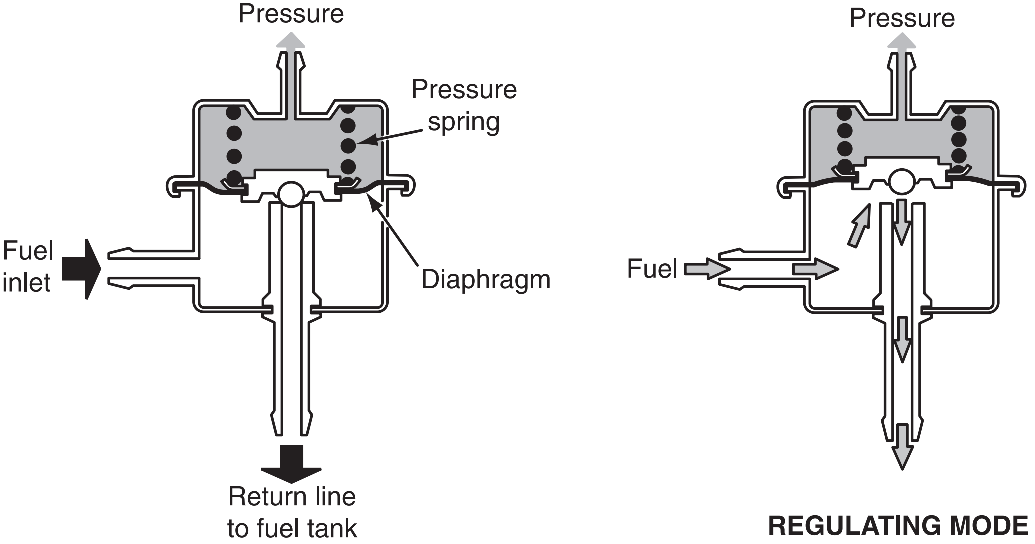


Figure 11–3 Operation of a diaphragm-operated fuel pressure regulator.

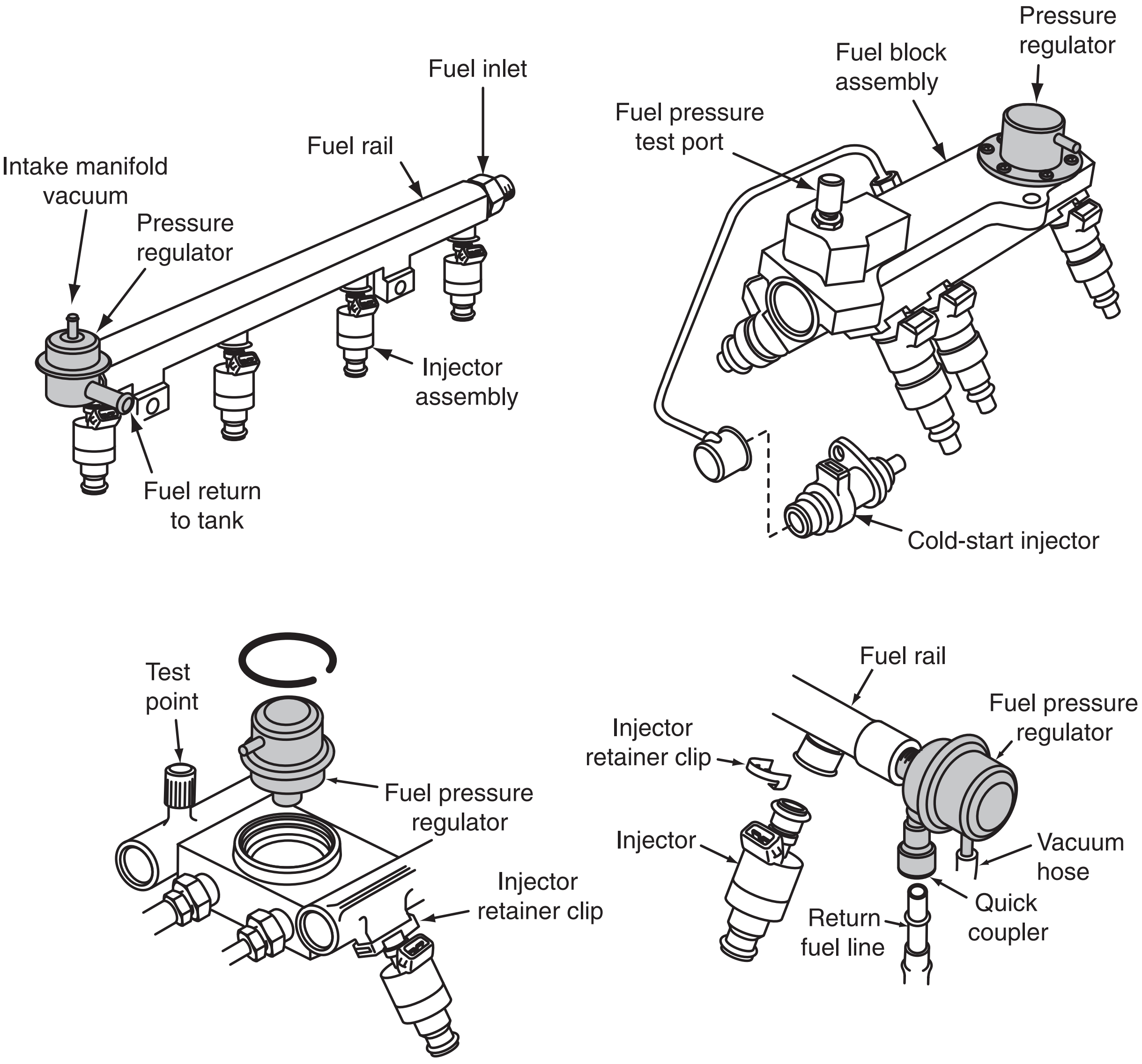


Figure 11–4 Fuel rail: 2.4-L, 2.8-L, 5.0-L, and 5.7-L engines.

rate will also be constant any time the injector is open. This leaves only one variable in controlling the air/fuel ratio: how long the PCM keeps an injector held open each time it energizes the injector. Many technicians incorrectly believe that the regulator is indexed to manifold vacuum to increase the *flow rate* at WOT and decrease the flow rate at idle. In fact, the regulator is indexed to manifold vacuum so that the flow rate will be held *constant* regardless of throttle position. This constant flow rate is programmed into the PCM's PROM chip. Thus, the base fuel calculations in PROM only have to calculate injector on-time (pulse width) when controlling the air/fuel ratio.

The manifold vacuum signal to the pressure regulator is only necessary on a PFI application because the outlet tip of the injector is located in the intake manifold *below the throttle plate(s).* GM (and most other) TBI applications do not require referencing the regulator to a vacuum signal because the outlet tip of the injector is located above the throttle plate(s) in a throttle body; this reduces or eliminates the effects of engine load in the throttle bore area. Thus, the fuel pressure on a TBI application does not need to vary with engine load because the pressure at the outlet tip of the injector is fairly consistent, resulting in a steady pressure differential.

In addition, by releasing excess fuel into a return line, the fuel pressure regulator keeps a constant stream of fuel flowing back to the tank to ensure that cool fuel from the tank is always supplied to the fuel rail and injectors. This, combined with the higher operating pressures, helps to reduce or eliminate the chance of vapor lock.

INJECTORS

An injector is installed in the intake port of each cylinder, with 70 to 100 mm between the tip of the injector and the center of the valve on V-type engines (Figure 11–5). The nozzles spray fuel in a 25-degree conical pattern. O-rings are used to seal between the nozzle and the fuel rail and between the nozzle and the intake manifold. The O-rings also serve to retard the heat transfer from the engine to the nozzle of the injector and to reduce nozzle vibration. The O-rings should be lubricated or replaced as necessary whenever the injectors are removed. A damaged or hardened O-ring may allow a fuel or vacuum leak. PFI systems are very sensitive to vacuum leaks.

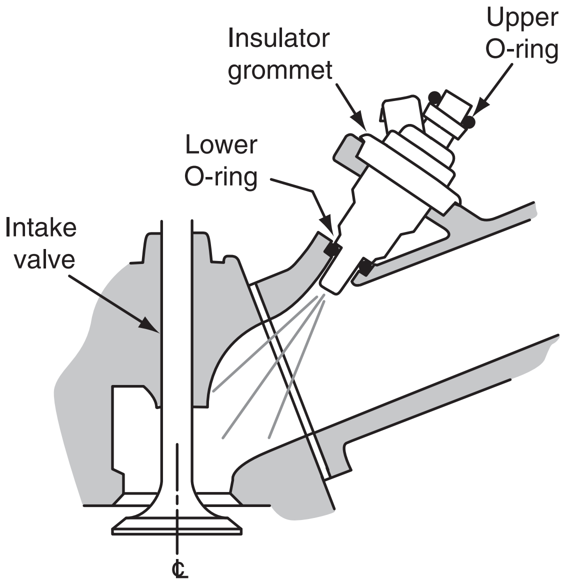


Figure 11–5 Port injection sprays fuel into the intake port and fills the port with fuel vapor before the valve opens.

THROTTLE BODY

The throttle body on a PFI system controls the amount of air allowed into the engine's induction system with a throttle blade and shaft controlled by the accelerator pedal, just as in a carburetor or TBI unit (Figure 11–6). In this case, however, only air passes the throttle blade. An idle stop screw determines how nearly closed the throttle blade is at idle. A TPS keeps the PCM informed as to the throttle valve's position. Idle speed is regulated by an idle air control (IAC) motor and valve assembly,

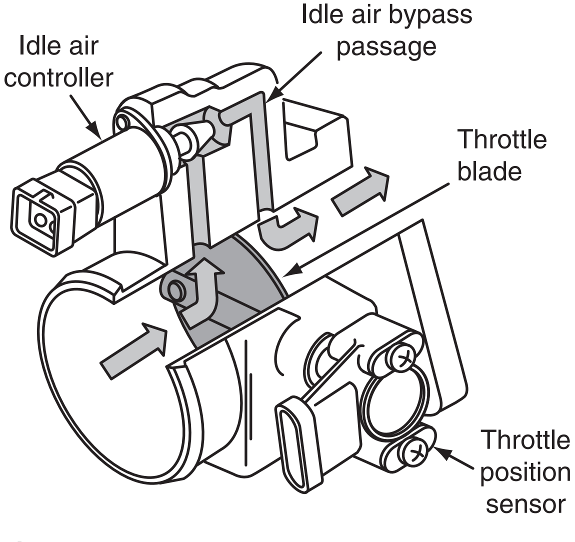


Figure 11–6 Throttle body assembly, 2.8-L engine.

which controls the amount of air allowed to bypass the throttle blade through a bypass passage and is, in turn, controlled by the PCM. Most throttle body units have a cavity for engine coolant to flow through to prevent throttle blade icing.

NON-PCM EMISSION CONTROLS

There is a growing trend in the automotive industry: As computerized engine control systems become more efficient, fewer traditional mechanical emissions control devices are needed. This is evidenced by the following list of non–PCM-controlled emissions control devices during the first or second year of PFI production:

- 1.8-L—canister purge, PCV, and internal EGR (no EGR valve)
- 2.8-L—PCV and deceleration valve (admits additional air during deceleration on manual transmission vehicles)
- 3.0- and 3.8-L—PCV
- 5.0- and 5.7-L—PCV

Diagnostic & Service Tip

An unexpected problem with PFI throttle bodies has been fuel deposits on the throttle blades. The source of these fuel vapors is fuel that drifts back from the intake ports when the engine is shut down hot. The heat vaporizes most or all of the residual fuel, and the coolest surface it encounters in the intake path is the throttle blade itself. The problem is that these deposits change the shape and size of the opening in the smallest throttle opening angles. This can adversely affect driveability in unexpected ways, such as hesitation, erratic idle, hard starting, and surging. The throttle blades can be visually inspected for such deposits and cleaned with solvent. Such inspection should be a routine maintenance task on cars with this fuel injection system.

INPUTS

Engine Coolant Temperature Sensor

This is the same sensor used in the C3 system, the Electronic Fuel Injection (EFI) system, and other GM electronic engine management systems. The engine coolant temperature (ECT) input affects control of:

- air/fuel mixture (in open loop)
- spark timing
- spark knock control (on some engines)
- engine idle
- torque converter lockup clutch actuation
- canister purge (except on the 1.8-L engine up to 1985)
- EGR (except for the 1.8-L engine up to 1985)
- cooling fan (on some vehicles, especially with transverse-mounted engines)

Mass Air Flow Sensor

Many General Motors PFI systems either use or have used an MAF sensor. In the mid-1980s, two MAF sensors were used: one on Buick engines and one on Chevrolet engines. Buick engines used an MAF manufactured by **AC,** a division of General Motors. Chevrolet engines used a Bosch unit. In the late 1980s, the AC unit was discontinued and a unit built by Hitachi of Japan was used on Buick engines. Chevrolet engines were by then no longer equipped with an MAF sensor.

AC MAF Sensor. The AC MAF sensor contains a screen to break up the air flow (Figure 11–7). After the air passes through the screen, it flows over an air temperature-sensing resistor. A sample tube then directs some of the air to flow over a heated foil sensing element. The power to heat the sensing element comes from a fuse or relay, depending on the application (Figure 11–8). The circuitry of the MAF sensor controls current flow through the foil sensing element, maintaining it at 167°F above the incoming air temperature, as measured by the temperature-sensing resistor. The power required to keep the sensing foil

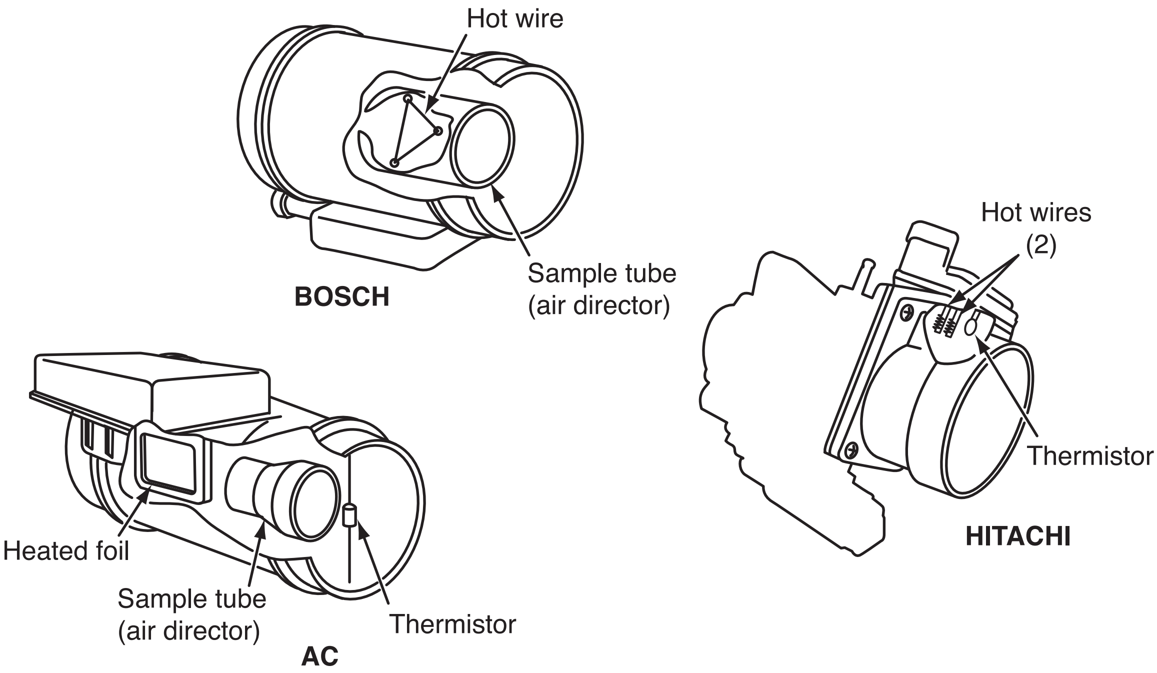


Figure 11–7 GM MAF sensors.

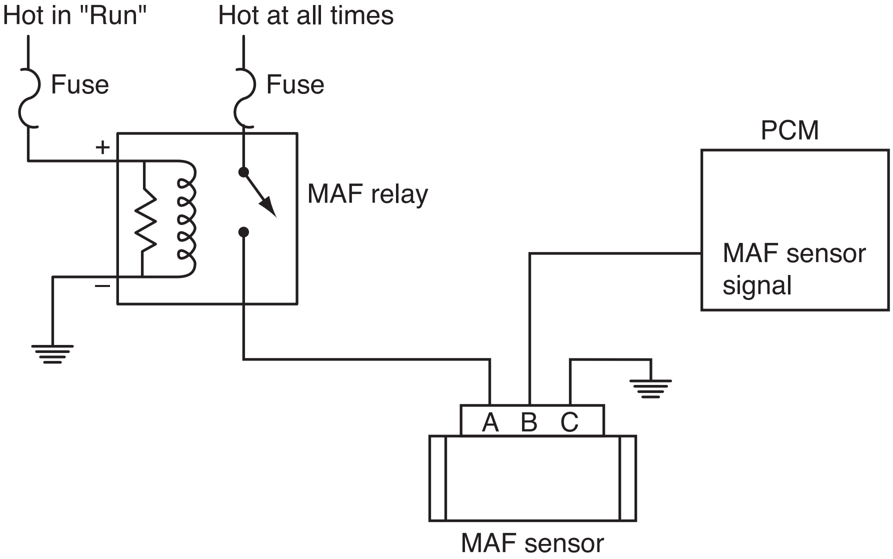


Figure 11–8 MAF relay circuit.

element 167°F above incoming air temperature is a measure of MAF. This value is sent to the PCM as a digital signal ranging in frequency from 30 Hz (cycles per second) to 150 Hz (150 Hz represents the highest MAF rate). The PCM compares the MAF sensor information to a preprogrammed look-up chart and finds air flow in grams per second. Using this value along with engine temperature and engine RPM, the PCM can calculate exactly how much fuel is required to achieve the desired air/fuel ratio. Mass air flow readings are taken and air/fuel mixture calculations are revised about 160 times per second.

Bosch MAF Sensor. The Bosch MAF sensor works much the same way as the AC unit except that a hot-wire element is used instead of a foil sensing element. Also, each time the ignition is turned off after the system has been in closed loop, a separate burn-off module momentarily puts enough current through the wire heat element to make it red hot (Figure 11–9). This burns off any residual accumulation, keeping the sensor accurate. It is critical that the sensor wire's surface be clean because any accumulation of deposits retards its ability to transfer heat.

Intake Air Temperature Sensor

The intake air temperature (IAT) sensor looks like and essentially is a coolant temperature sensor with its thermistor sensing element exposed to the intake air instead of being fully enclosed like the ECT sensor. It screws into a hole in the intake manifold or, on some vehicles, into the air-cleaner housing. The perforated nose extends inside. Although it is not used on all applications, it influences air/fuel mixture, spark timing, and idle speed control on those engines that use it.

Throttle Position Sensor

The throttle position sensor (TPS) is a potentiometer mounted on the side of the throttle body and attached to the end of the throttle

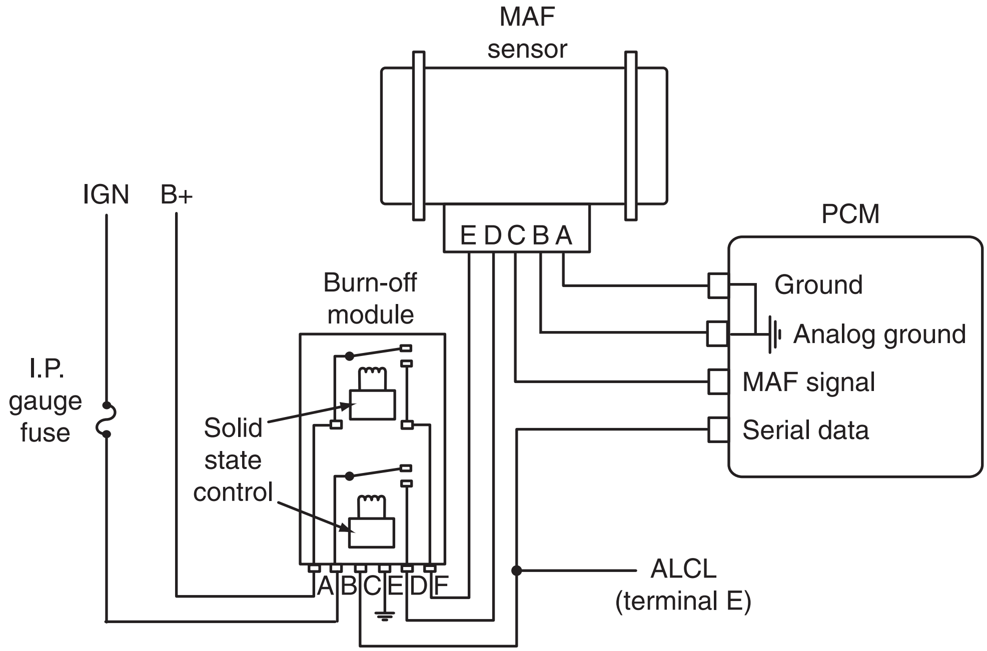


Figure 11–9 Bosch MAF circuit and burn-off module.

C3I System

For many years, automotive engineers generally felt that it did not make much difference *when* the fuel was sprayed into the intake port as long as precisely the *right amount* of fuel was sprayed. When you consider how fast all of this happens (the intake valve opens and closes 25 times per second at 3000 RPM), it would not seem to make much difference.

With the introduction of the **Computer Controlled Coil Ignition (C3I)** system by Buick in 1984—and since extended to most other divisions—it became necessary to employ a sequential fuel injection (SFI) system. This is because the C3I fires two plugs at one time; one at the regular spark advance position at the end of the compression stroke, the other at the cylinder 360 degrees out of sequence with the first, the cylinder just completing its exhaust stroke. This is the waste spark system explained in the "Outputs" section of this chapter. The second "waste" spark serves no purpose in combustion; it is just an unavoidable by-product of the ignition system's electrical design. If, however, a pressurized combustible mixture (the first applications of C3I were on turbocharged engines) was just on the other side of the open intake valve, a backfire could occur in the intake manifold. To avoid this, each injector pulse is timed so the fuel is immediately purged from the manifold by its respective cylinder's intake stroke.

GM rapidly expanded the application of SFI to other engines, regardless of whether the ignition system design used a distributor, was a waste spark design, or had one coil per each cylinder. Similarly, Ford introduced SFI in 1986 on their 5-L engines. And by the mid-1990s most manufacturers had incorporated SFI on all of their gasoline engines.

shaft (Figure 11–6). Its input affects most PCM-controlled functions including fuel management, spark timing, IAC, torque converter lockup clutch engagement, and air-conditioning (A/C) control.

Reference Pulse

On all but those engines equipped with a distributorless ignition system, the REF signal comes from the distributor pickup coil. Without this signal the engine does not start or run because without it the PCM will not pulse the injectors.

The distributorless ignition systems use sensors to provide information to the ignition module regarding crankshaft and camshaft position and speed. The C3I systems use Hall effect switches; both the Direct Ignition System (DIS) and Integrated Direct Ignition (IDI) systems use a permanent magnet pulse generator (Figure 11–10).

C3I System. There are three different versions of the C3I system: Type I, Type II, and Type III. Each of the three types uses a Hall effect switch mounted behind the crankshaft balancer (Figure 11–11). The balancer has three vanes, equally sized and equally spaced, which are positioned to form a circle extending back toward the engine. As the crankshaft turns, the vanes alternately pass through the Hall effect switch, producing a signal that is fed to the PCM and the ignition module. When used on the 3.0-L engine, the Type I system uses a second Hall effect switch mounted behind the crankshaft balancer with a single vane extending back, nearer the outer circumference of the balancer. This vane and its sensor identify which piston pair is approaching TDC.

The Type I and Type II systems, when used with the 3.8-L turbo engine, include a Hall effect switch mounted in what used to be the distributor

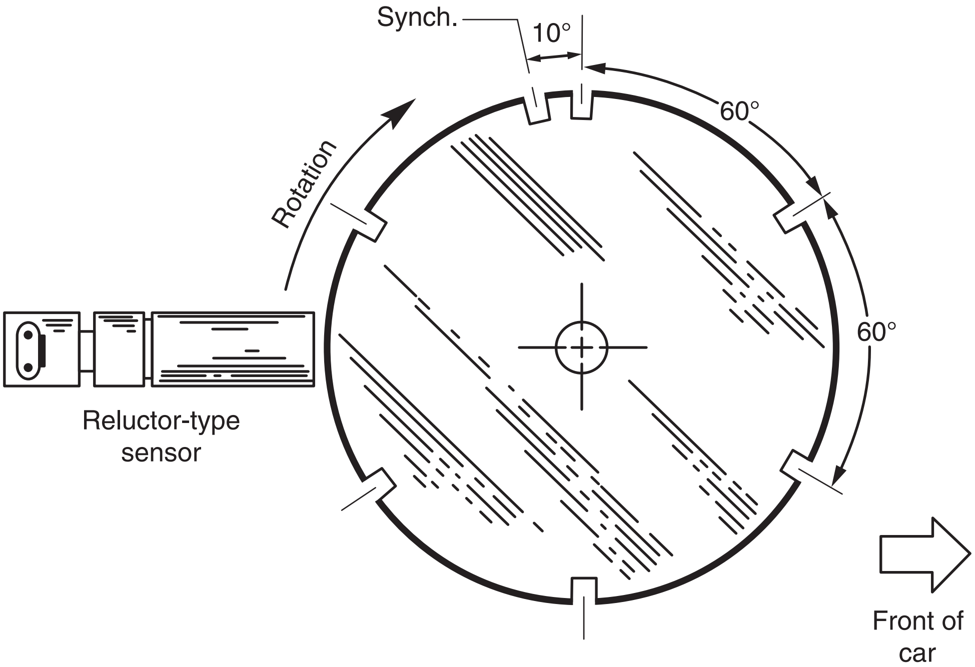


Figure 11–10 Crankshaft position sensor.

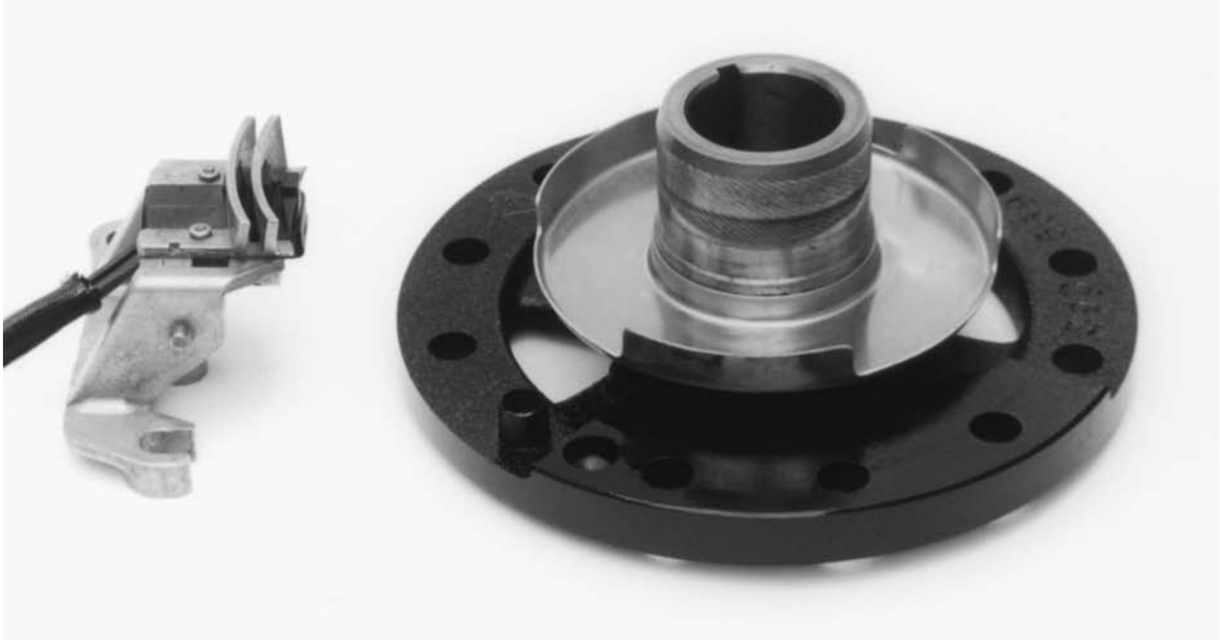


Figure 11–11 Hall effect crankshaft sensor and harmonic balancer with three vanes and three windows.

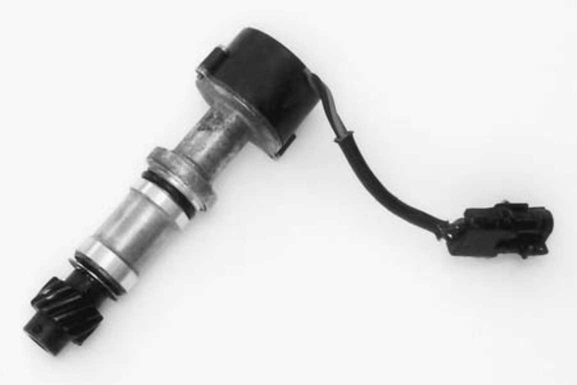


Figure 11–12 Hall effect camshaft position sensor that mounts in the distributor hole.

hole to serve as a camshaft position sensor (Figure 11–12). The vane cup in this sensor assembly has one large vane and one small window that rotate through the Hall effect switch. This sensor is driven by the camshaft at the same speed (unlike the harmonic-balancer mounted sensor, which signals at crankshaft speed). When used on the 3.8-L non-turbocharged SFI engine, these same two systems use a Hall effect cam sensor mounted in the timing cover; they are triggered by a magnet attached to the camshaft timing gear. The cam sensor signal alerts the PCM when the number-one cylinder is at TDC so it can start the firing order over again and time the injector pulses. Loss of this signal results in a code 41 being set. If the signal is absent or lost during cranking, the engine will not start; if the signal is lost while the engine is running, the engine will continue running but will not restart. In more recent General Motors literature, the camshaft position sensor is referred to as a “sync sensor.”

The Type III system, sometimes referred to as the “Fast Start,” also has its sync sensor located in the timing cover. On this system, a third sensor is used:—A Hall effect switch located behind the harmonic balancer, along with the crankshaft sensor. This sensor, referred to as the *Crank 18x sensor,* is triggered by 18 evenly spaced interrupter vanes protruding rearward from near the outer circumference of the balancer. The 18 vanes are each 10 degrees wide and are spaced by 10-degree windows, resulting in a total of 36 voltage transitions per crankshaft rotation, one every 10 degrees (Figure 11–13). These signals are sent to the ignition module, which, in turn, sends them on to the PCM.

On this system, the crank sensor is called the *Crank 3x sensor.* Its three interrupter vanes, nearer the center on the balancer, are not symmetrical as they are on the other C3I systems. The windows between the vanes are 10, 20, and 30 degrees wide, as shown in Figure 11–13. The signal produced by the leading and trailing edge of each window constitutes a 3X pulse. The number of 18X signals that occurs during each 3X pulse enables the PCM to determine which 3X pulse it is reading. There is one 18X signal during the 10-degree window pulse, two during the 20-degree window pulse, and three during the 30-degree window pulse. This enables the PCM to determine which coil should be fired next within the first 120 degrees of crankshaft rotation. This system provides the following advantages:

- faster starts, because the PCM can identify cylinder position more quickly
- more accurate REF signals to the PCM, especially at low speeds
- increased run reliability, as the engine can continue to operate without the cam sensor
- the ability of the PCM to read crankshaft acceleration and deceleration rates

DIS and IDI Systems. Both the IDI and the DIS use a magnetic pulse generator on the crankshaft instead of the Hall effect switches for crankshaft reference (position and speed). The crankshaft for those engines that use either the DIS or IDI system has a round steel disc machined into its center. This disc is concentric to the crankshaft’s center line at its center counterweight (Figure 11–14). The disc, called a *reluctor,* has seven notches cut into it. The term reluctor refers to any device that changes the

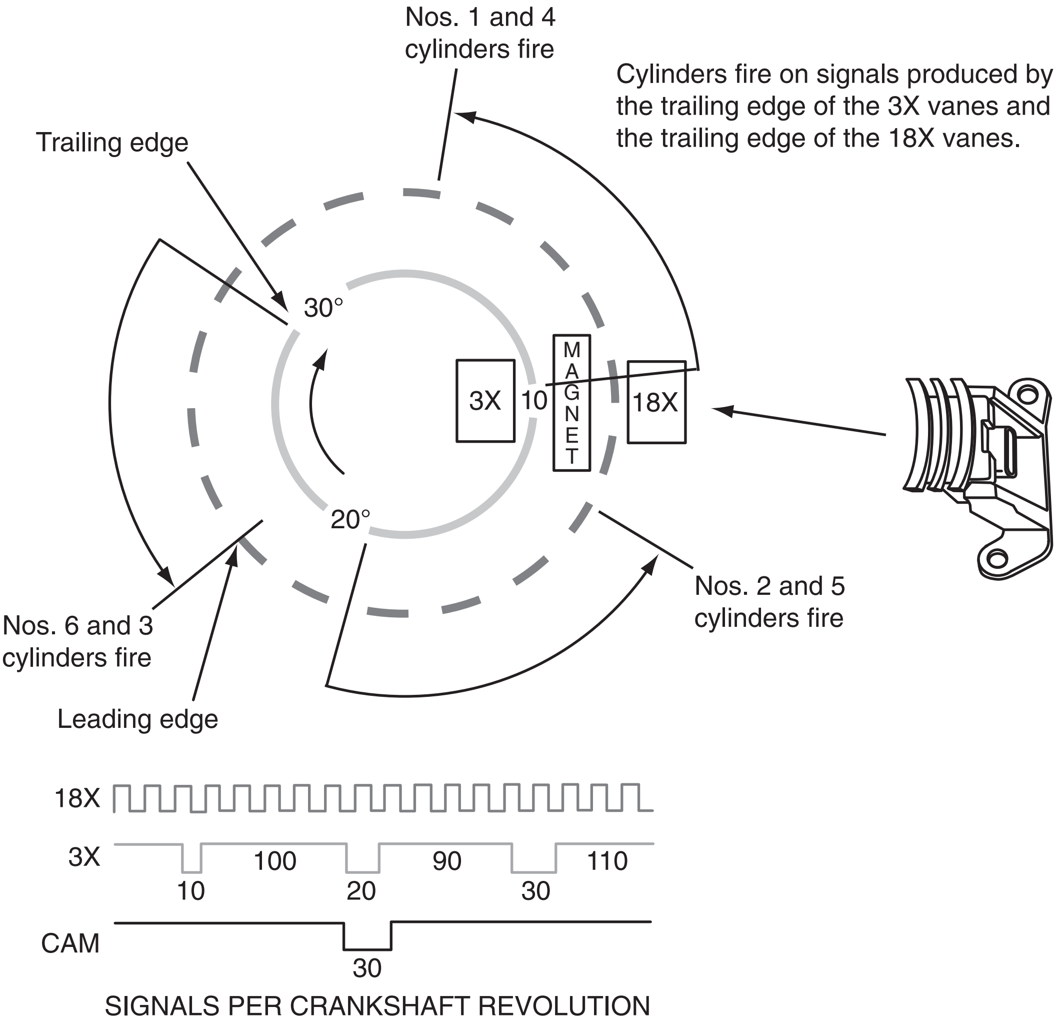


Figure 11–13 Combination sensor for C3I (type III) Fast Start.

reluctance of a material to conduct magnetic lines of force. The same reluctor is used on both four- and six-cylinder engines. The crankshaft sensor is mounted to the engine block and extends through a hole in the crankcase. Its tip, containing a permanent magnet and a wire coil, is spaced 0.050 inch from the reluctor.

Six of the reluctor's seven notches are spaced evenly around it at 60-degree intervals (Figure 11–14). The seventh notch, called the *sync* notch, is located between notches 6 and 1, 10 degrees from notch 6 and 50 degrees from notch 1. Because of its placement at an odd position in relation to the other notches, the sync notch provides an irregular signal that the module can identify. The module uses this signal to synchronize the coil-firing sequence to the crankshaft's position in the engine cycle.

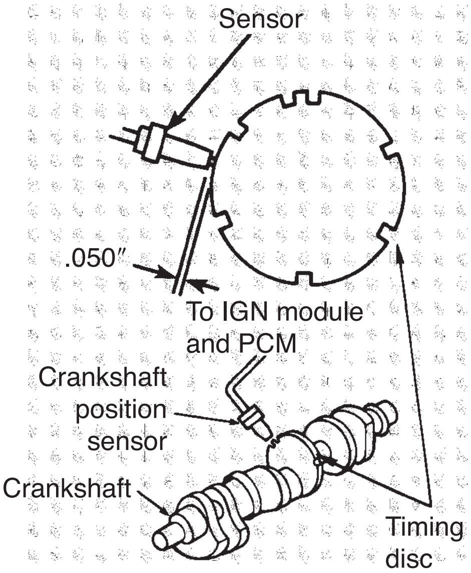


Figure 11–14 Crankshaft reluctor wheel.

On both the DIS and IDI systems, the notch that produces the signal that results in the appropriate coil being fired during module mode operation is often referred to as the *cylinder event* notch. When the engine operates in the electronic spark timing (EST) mode, the PCM uses this signal as an input for calculating:

- ignition timing while operating in EST mode
- fuel injector pulses

GM's Opti-Spark Distributor

In 1992, GM introduced an optical distributor on the Corvette, similar to those already in use by Chrysler on their Mitsubishi engines, as well as Nissan vehicles. The GM Opti-Spark distributor is located at the front of the engine just behind the water pump, thus explaining its overall flat design (Figure 11–15). Like its counterparts, this sensor has two photo diodes placed opposite two LEDs that monitor two sets of slots in a slotted wheel (Figure 11–16). When light is allowed through a slot to strike the photo diode, a voltage pulse is produced. The optical sensor assembly used in the GM optical distributor is manufactured by Mitsubishi, as are many of those used in the Chrysler and Nissan optical distributors.

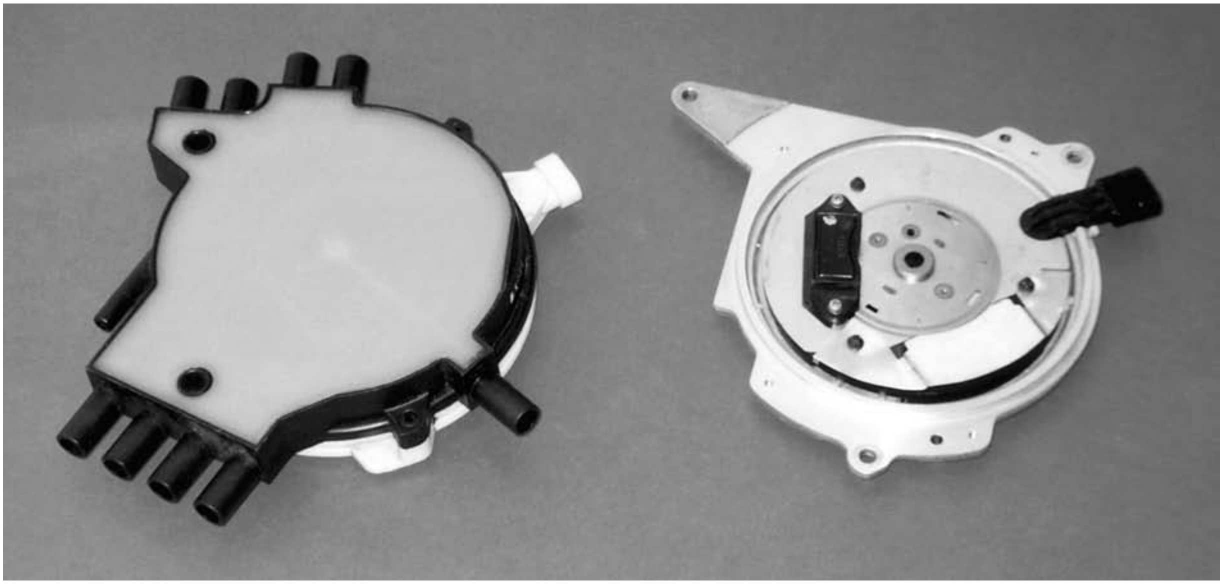


Figure 11–15 Opti-Spark distributor.

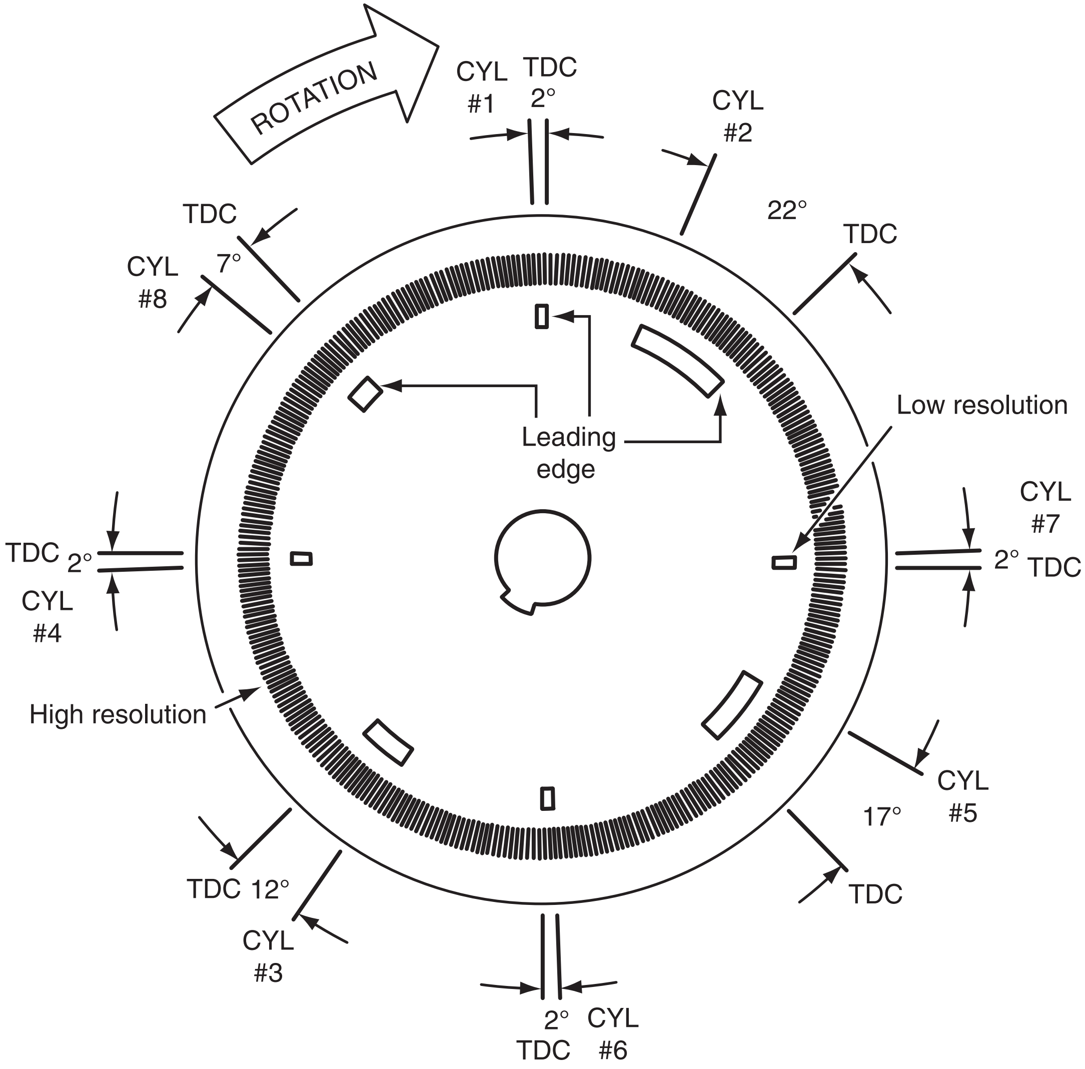


Figure 11–16 Opti-Spark sensor disk.

The outer row has 360 slots, one for every degree of distributor rotation, which produces the high-resolution signal. The inner row has one slot for every cylinder—eight slots for the V8 application. This produces the low-resolution signal. This is the concept behind the Chrysler and Nissan optical distributors, as well. Unlike Chrysler, whose PCM determines where the number-one cylinder is from the high-resolution signal, GM and Nissan systems identify the number-one cylinder from the low-resolution signal. On GM's version, the low-resolution slots are different sizes in degrees of rotation (Figure 11–16). By comparing these slots to the high-resolution slots, the PCM identifies the location of each of the cylinders, providing the information that the PCM needs to control the fuel injectors sequentially.

Oxygen Sensor

This oxygen sensor is the same single-wire sensor used on other General Motors vehicles. In some vehicles in later model years, multi-wire sensors are used, both to provide independent ground circuits and to provide electric-resistance heat to the sensor to put the system into closed loop more quickly.

Like the oxygen sensor circuit described in Chapter 10, the PFI system also uses a PCM-generated 450-mV signal, known as a *bias voltage,* which it places on the oxygen sensor signal wire. The PCM places the bias voltage on the oxygen sensor signal wire whenever the engine is started and until the O_2S begins to generate its own voltage. The PCM's voltage-sensing circuits continue to watch this voltage signal. As the engine is warming up, eventually the voltage begins to exceed the 450-mV bias voltage placed on this circuit, at which point the PCM knows that the O_2S is hot enough to begin generating its own voltage; the PCM will then remove the bias voltage signal and watch the voltage that the O_2S is placing on this circuit. Therefore, when watching the O_2S voltage values with a scan tool immediately after a cold engine start, expect to see a value of 450 mV, even before the oxygen sensor is hot enough to operate.

Vehicle Speed Sensor

The two types of vehicle speed sensor (VSS) discussed in Chapter 10 are also used on this system.

EGR Diagnostic Switch

On PFI systems that control EGR operation, an EGR diagnostic switch is used to tell the PCM whether the EGR is actually being applied when it is commanded to apply. Two types are used: The four- and six-cylinder engines use a vacuum-operated switch that is tied into the vacuum control line between the vacuum control valve and the EGR valve. It is physically part of the vacuum control valve and monitors vacuum applied to the EGR valve. It closes when a vacuum signal is sensed.

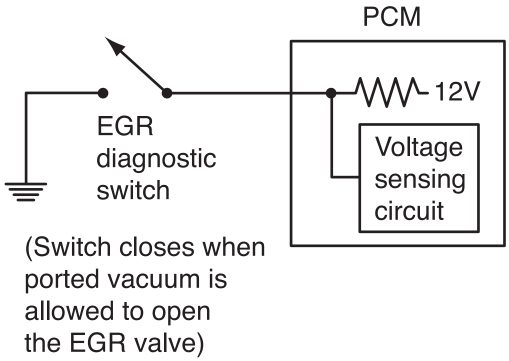

PCM
12V
EGR diagnostic switch
Voltage sensing circuit
(Switch closes when ported vacuum is allowed to open the EGR valve)

Figure 11–17 EGR diagnostic switch circuit.

The 5.0- and 5.7-L engines use a thermal switch for exactly the same purpose as the vacuum switch used on the smaller engines. It, however, screws into the base of the EGR valve. If the EGR valve is open, the heat of the exhaust gasses flowing past the heat-sensing tip of the thermal switch causes the switch to close. With either type of EGR switch, a 12-V reference signal is supplied by the PCM and is grounded out by the closing of the switch, thereby pulling the voltage signal low (Figure 11–17).

Detonation Sensor

Most of the General Motors PFI systems incorporate an electronic spark control (ESC) system using a piezoelectric knock sensor, as described in Chapter 10.

Park/Neutral Switch

The park/neutral (P/N) switch, which can be located near the shifter assembly or in the transmission itself, is normally open while driving. When the vehicle is shifted into park or neutral, it closes. The PCM monitors the P/N switch and thus knows whether the transmission is in gear. This information is used to help control engine idle and EGR control.

Air-Conditioning Switch

On PFI cars equipped with A/C, the A/C control switch on the instrument panel connects through a wire to the PCM. When the A/C is turned on, the voltage signal travels from the A/C switch to the **pressure cycling switch** to the PCM. Some systems also put the **high-pressure cutout switch** in series in the same circuit. This signal tells the PCM that the A/C switch is on and the pressure cycling switch is closed. The PCM uses this information to turn on the A/C relay and/or adjust the IAC valve.

Transmission Switches

Transmissions used in PFI-equipped vehicles have one or more hydraulically operated electric switches screwed into the valve body. These switches provide the PCM with signals indicating what gear the transmission is in. This information enables it to more effectively control torque converter lockup clutch operation.

Cranking Signal

On some engines, a wire from the starter solenoid circuit feeds a cranking signal to the PCM to alert it that the engine is being cranked. This puts the system in cranking mode and leads to an enriched air/fuel mixture for easier starting. On other engines, the cranking signal is fed to the cold-start injector in the intake manifold and provides the necessary enrichment through that mechanism. The cold-start injector, on vehicles where it is used, is not controlled by the PCM.

System Voltage/Fuel Pump Voltage

The PCM monitors system voltage through one of its battery voltage inputs. If voltage drops below a preprogrammed value, the system goes into battery voltage correction mode. Some PFI systems have a wire from the positive side of the fuel pump power circuit to the PCM (Figure 11–18). If this signal is not present when the PCM first energizes the fuel pump relay as the ignition is turned to run, code 54 is stored in the PCM's memory.

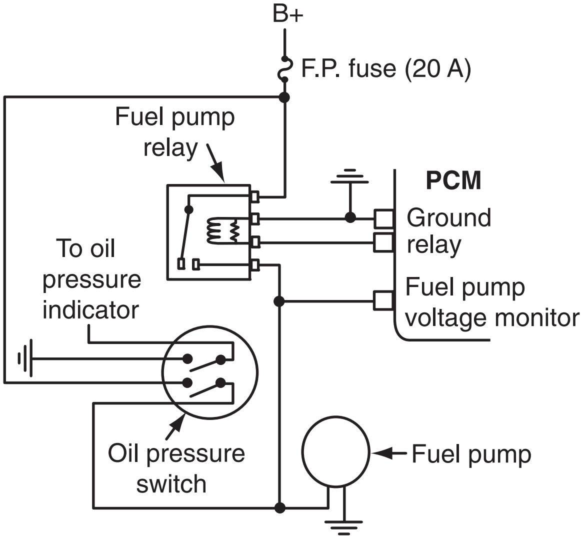


Figure 11–18 Fuel pump control circuit (typical).

Power Steering Switch

A power steering (P/S) switch is used on PFI systems to alert the PCM when P/S pressure is high enough to significantly affect engine idle performance (because of the momentary high load) (Figure 11–19). The P/S switch is normally open; it closes in response to high P/S pressure. When the switch is open, feedback voltage to the PCM is about 12 V; when the switch closes, voltage falls below 1 V. Also, when the switch closes, the PCM increases idle air bypass and retards ignition timing. On some systems, the A/C compressor clutch is also disengaged (to reduce idle load).

Body Control Module 800 Circuit

Some late-model PFI applications also feature a body control module (BCM) similar to the one introduced on the Cadillac DFI system. The

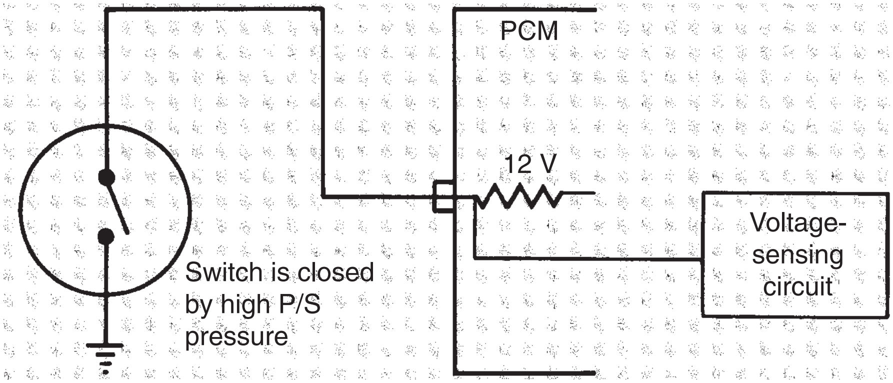


Figure 11–19 P/S switch (typical).

BCM controls A/C and other systems such as a driver information center. The driver information center displays information about fuel economy, elapsed time, distance to destination, time, date, and so forth. The BCM shares information with the PCM. For instance, the PCM may send the BCM information about vehicle speed, coolant temperature, or when the vehicle is operating at WOT. The BCM can send the PCM such information as outside air temperature, the temperature in the high-pressure side of the A/C system, or when the rear window defog system is on.

This information is transmitted over a wire between the two computers. The wire is called a *data bus.* If information can be transmitted both ways over the same wire, it is called a *bidirectional data bus.* General Motors refers to this data link on 1980s applications as *Circuit 800.* Circuit 800 also extends to modules that the BCM and PCM communicate with (Figure 11–20). See Chapter 9 for more information on data busses and multiplexing.

Cruise Control

When cruise control is engaged, the PCM is notified by the cruise control module. The PCM uses this information to modify its control of the torque converter lockup clutch.

OUTPUTS

Injectors

The fuel injector is a solenoid-operated nozzle controlled by the PCM (Figure 11–21). The PCM pulses it by grounding the return side (low-voltage side) of the injector circuit (Figure 11–22). Fuel under nearly constant controlled pressure is sprayed past the open needle and seat assembly into the intake port of each cylinder. On all except SFI applications, all injectors are simultaneously pulsed once per crankshaft revolution. The design of the intake manifold is such that any fuel sprayed while the intake valve is closed simply sits and vaporizes until the intake valve opens. The SFI system pulses each injector individually, once per engine cycle, in the firing order (Figure 11–23). During each pulse the injectors are held open for about 1 or 2 ms at idle (depending on coolant temperature), to perhaps 6 or 7 ms at WOT (1 ms equals 1/1000 of a second).

Multec Injector. Rochester Products, a division of General Motors, has developed a new style of injector for multipoint injection systems (Figure 11–24). It is referred to as a *Multec,* which is short for *multiple technology injector.* This injector features a lower opening voltage requirement (important during cold weather cranking), fast

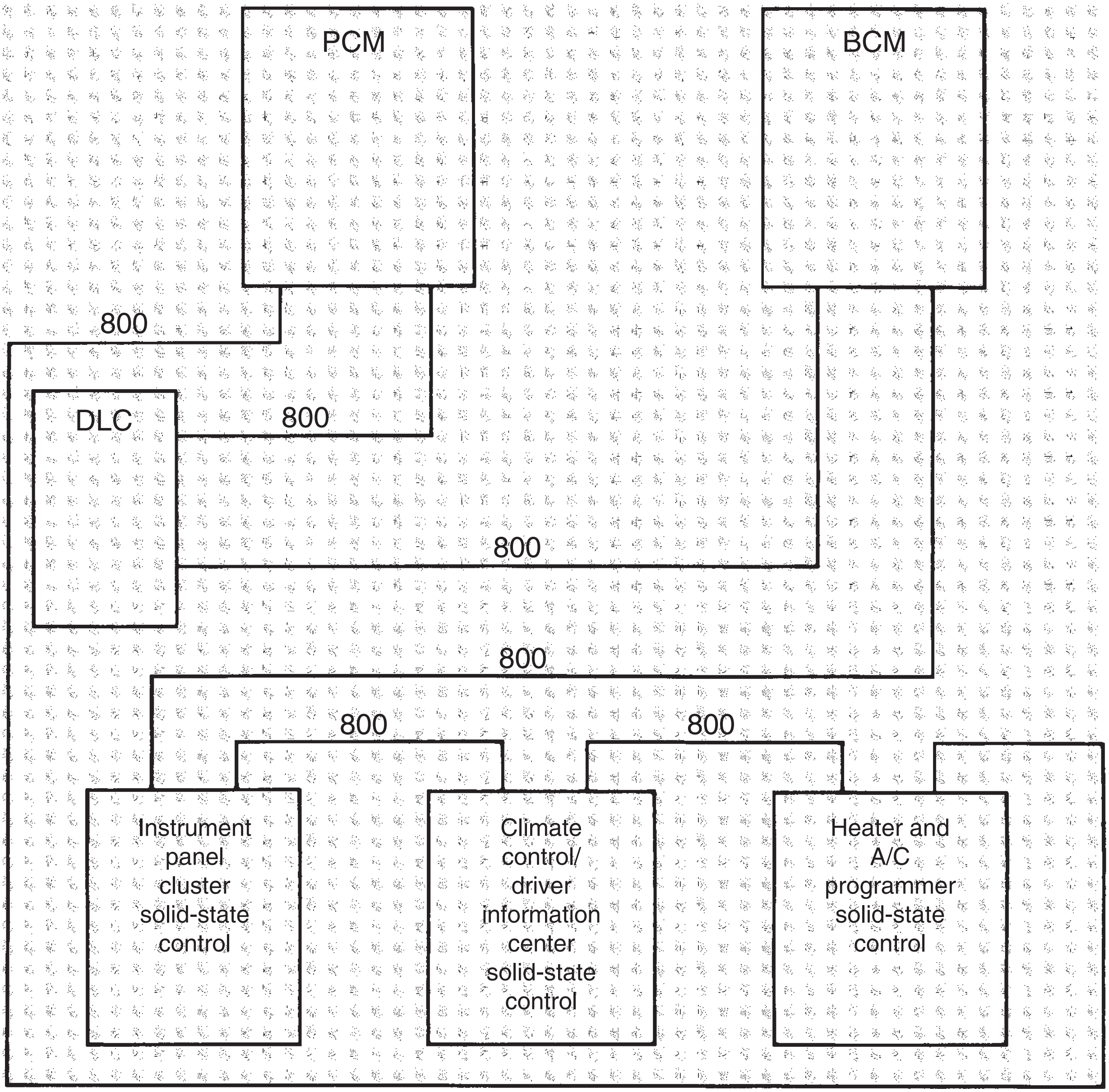

PCM
BCM
800
DLC
800
800
800
800
800
Instrument panel cluster solid-state control
Climate control/ driver information center solid-state control
Heater and A/C programmer solid-state control

Figure 11–20 Circuit 800.

response time, better fuel atomization, improved spray pattern control, and less susceptibility to fouling due to fuel blends or contamination. The traditional pintle (needle valve) is replaced with a ball shape on the solenoid core, as shown in Figure 11–21. When the ball is lifted off its seat, fuel sprays through the seat opening and past the director plate into the intake port.

Cold-Start Injector. The cold-start injector is controlled by a thermal time switch screwed into the engine water jacket (Figure 11–25). When the starter solenoid is engaged, voltage is

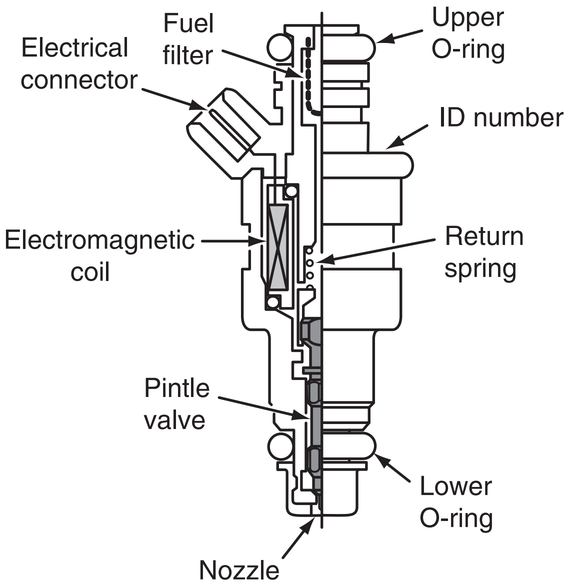


Figure 11–21 Injector (cutaway).

applied to circuit 806 by way of the crank fuse. Circuit 806 powers a heat element in the **thermo-time switch.** Circuit 806 also supplies voltage to the cold-start injector. Ground for the cold-start injector is provided by a bimetallic switch in the thermo-time switch. If the bimetallic switch is cool and closed when voltage is applied to the injector, the injector is activated. As soon as voltage is applied to the injector, however, it is also applied to the heat element in the thermo-time switch. If the coolant is at 68°F (20°C) or below, the bimetallic switch stays closed for a maximum of 8 seconds before the heat from the heat element opens the control switch. So the cold-start injector turns on for a maximum of 8 seconds or less, depending on coolant temperature, while and only while the engine is cranking. If the engine is started hot, of course, the cold-start injector does not come on at all.

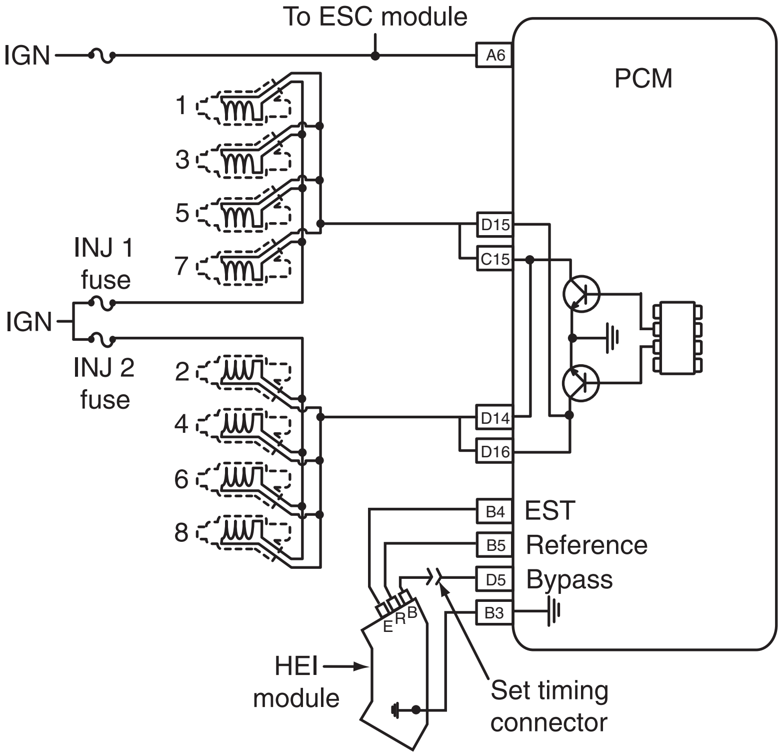


Figure 11–22 Injector control circuit.

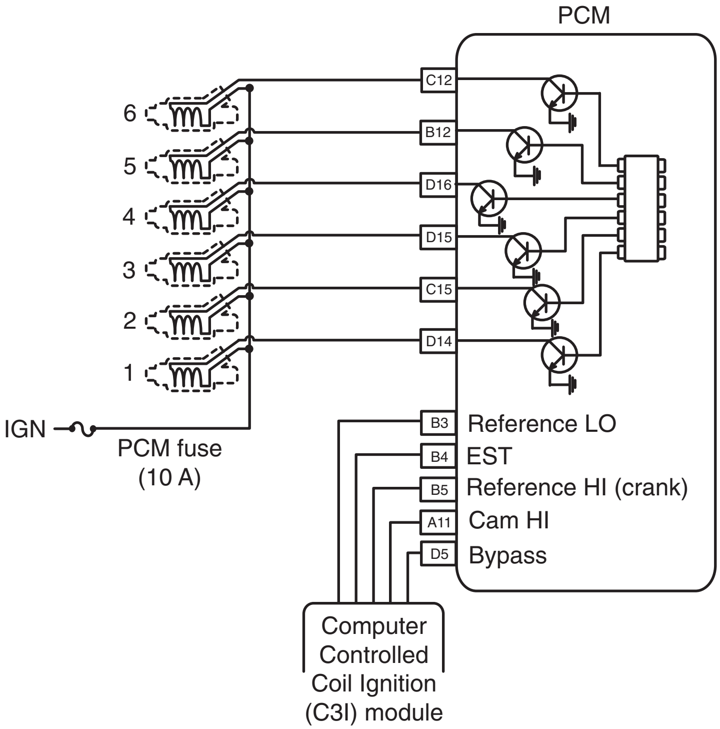


Figure 11–23 Electrical schematic of a typical SFI circuit.

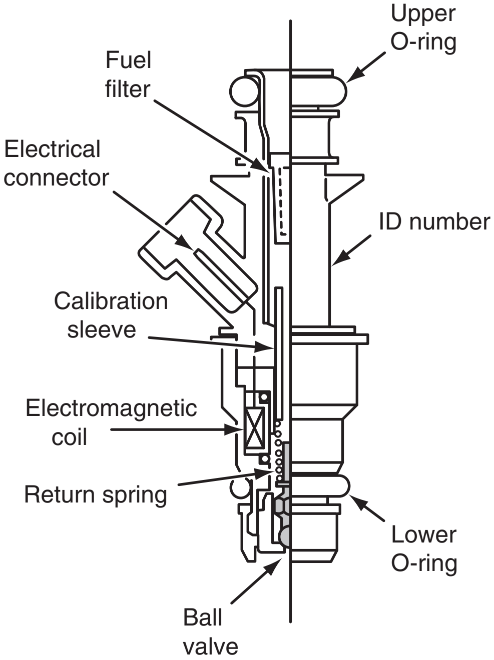


Figure 11–24 Multec injector.

Electric Fuel Pump

Other than providing a higher fuel pressure, the fuel pump for the PFI system operates and is controlled just like the pump for the EFI system. Greater fuel pressure allows finer atomization of the fuel and resists vapor lock problems more effectively.

Central Port Fuel Injection Systems

Central Multiport Fuel Injection. In the mid-1990s, General Motors introduced a new port fuel injection system known as **Central Multiport Fuel Injection (CMFI)** on Vortec engines. This system uses an injector assembly that consists of a fuel metering body, a fuel pressure regulator, and a single TBI-style fuel injector, which is connected to individual poppet nozzles (one per cylinder) with nylon fuel tubes (Figure 11–26). This assembly is housed in the lower portion

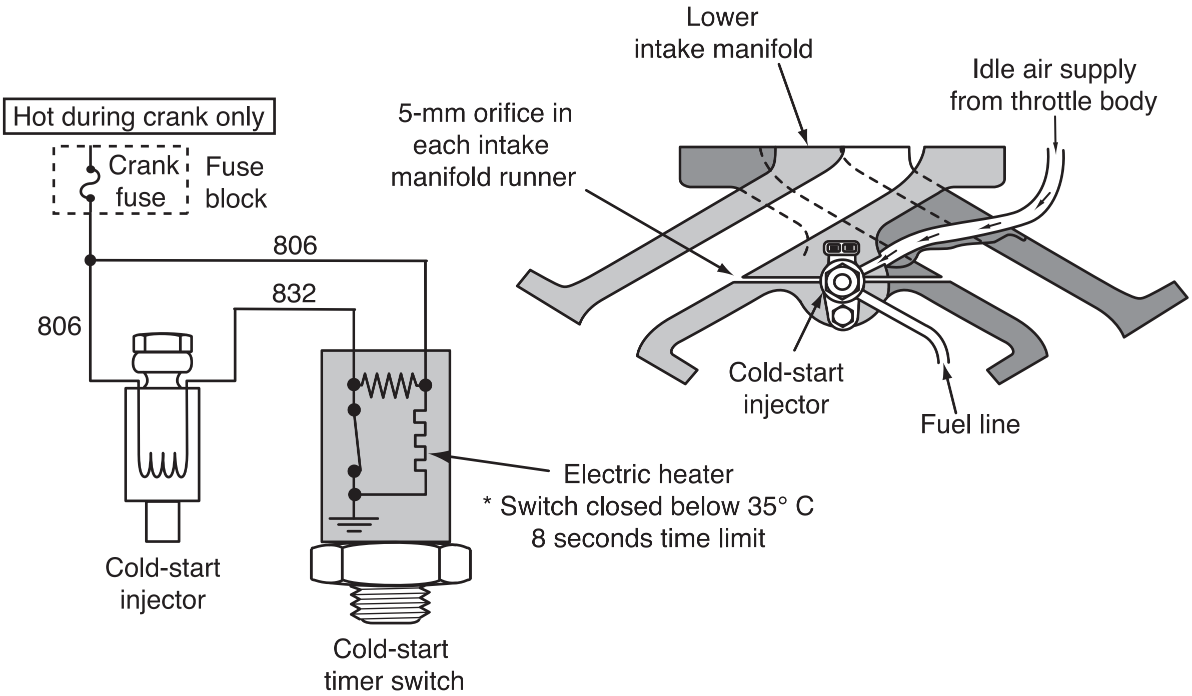


Figure 11–25 Cold-start injector control circuit (typical).

of a dual intake manifold assembly. The poppet nozzles, as in Figure 11–27, are simple, nonelectric, spring-loaded valves (normally closed) that are opened by applied fuel pressure from the single fuel injector solenoid. When opened, each poppet nozzle sprays fuel to the back side

Diagnostic & Service Tip

Although fuel injectors have no difficulty spraying fuel when they are clean and open, experience has shown that certain brands and blends of fuel are not entirely compatible with the conditions under which the injectors operate. In particular, the less volatile compounds in the fuel tend to remain on the tip of the injector and in the pintle and seat opening as the engine is shut off. The heat of the engine then hardens the residue into deposits that can limit the spray quantity or even degrade the spray pattern so as to prevent proper vaporization. Since this problem is usually not identical at each cylinder of the engine, the quantity sprayed and the quality of the spray patterns gradually begin to vary among the engine's injectors. The system, of course, does not include measures to identify which cylinder is spraying rich or which is spraying lean, so the computer has to work with the average mixture feedback signal it gets from the oxygen sensor. When the fuel injectors' delivery volume varies by more than about 3 percent, however, there is no pulse-width setting that will deliver the correct mixture. In these cases, only fuel injector cleaning with special chemicals or fuel injector replacement will clear up the delivery problem.

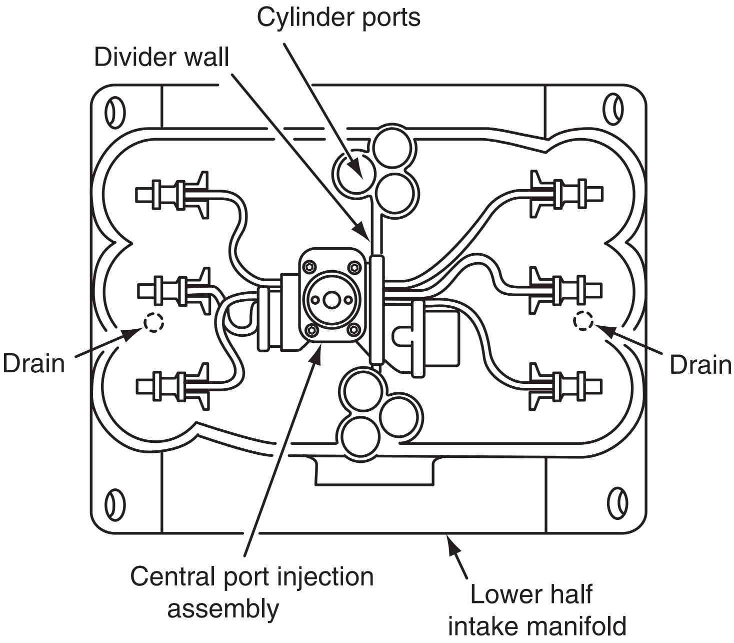


Figure 11–26 CMFI components in the lower half of the intake manifold.

of its intake valve until fuel pressure is reduced enough to allow it to close. The PCM controls fuel delivery through all poppet nozzles by controlling the on-time of the single injector solenoid.

Another interesting feature is that the fuel pressure regulator is able to maintain a steady pressure differential across the injector and poppet nozzles without the existence of the normal vacuum hose used to index most fuel pressure regulators to manifold pressure/vacuum. This is because it is located, as part of the fuel metering body, down in the lower intake manifold with its diaphragm already open to manifold pressure or vacuum (Figure 11–28).

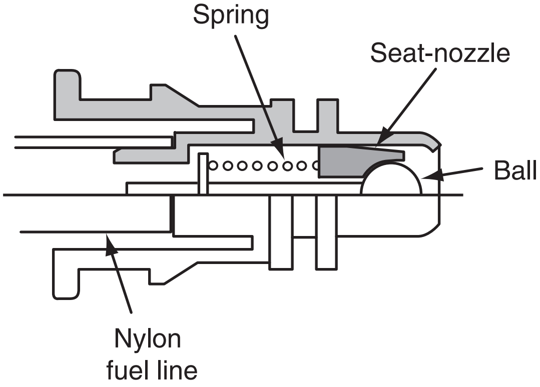


Figure 11–27 Poppet nozzle internal design.

The fuel injector solenoid in this assembly is operated as a peak and hold injector, as are most TBI-type fuel injectors. The injector's winding has low resistance (about 1.5 ohms), which allows more current to flow and thus provides faster response when it is energized by the PCM. Once opened, the PCM reduces the injector's current flow to prevent overheating of the solenoid winding, while maintaining enough current to keep the injector open for the remainder of its intended pulse.

Central Sequential Fuel Injection. General Motors has also introduced a sequential version of CMFI known as **Central Sequential Fuel Injection (CSFI)** (also known as CSI). This design is very similar to CMFI, except that each poppet nozzle is connected through its nylon

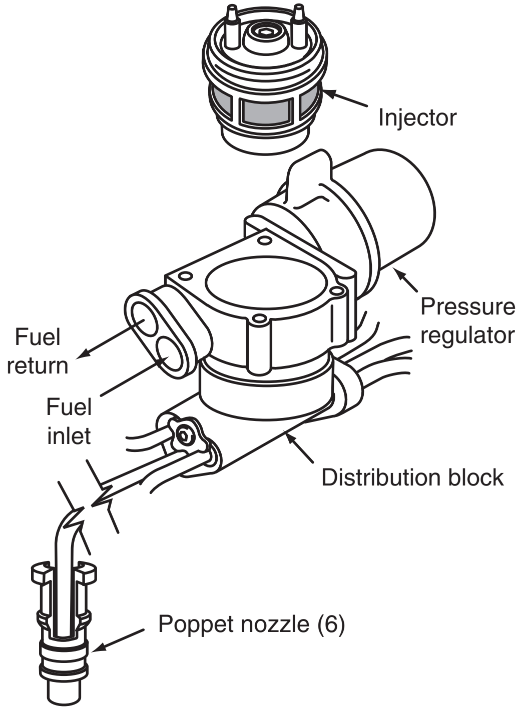


Figure 11–28 Central port injection components.

tube to an individual fuel injector solenoid within the fuel metering body, which is pulsed sequentially by the PCM.

Central Port Fuel Injection Demise. The Vortec engines that initially used the CMFI system, followed by the CSFI system, were redesigned by the late 1990s to use a traditional sequential port injection system with an external fuel rail and injectors, as is typical on most other vehicles.

Electronic Spark Timing/Distributorless Ignition Systems

EST maintains optimum spark timing under all conditions of engine load, speed, temperature, and air density or mass. The distributor-type ignition systems used on PFI engines operate the same as those discussed in Chapter 10, except that none of them use Hall effect switches.

Given the developments we have seen in computerized engine controls, there is no need to continue using a distributor with its tendencies toward wear and mechanical failure because:

- Reference signals can be taken directly from the crankshaft and camshaft.
- An ignition module can be mounted almost anywhere in the vehicle.
- Spark advance can be more effectively optimized by a fast microprocessor.
- Secondary spark distribution can be managed by separate coils and a module.

This should not be very surprising. After all, even the old points-and-condenser distributors were essentially nothing more than camshaft position sensors, combined with a simple mechanical/vacuum spark advance calculator and an on/off switch.

The term *distributorless ignition system* has come to be used as a generic label for an ignition system that does not use a distributor and may be abbreviated in some literature as DIS. However, General Motors most often uses the same abbreviation for *their Direct Ignition System,* one of their specific distributorless ignition systems. General Motors has introduced several different distributorless ignition systems on various engine applications:

- C3I (Computer Controlled Coil Ignition, of which there are three subtypes)
- DIS (Direct Ignition System)
- IDI (Integrated Direct Ignition)

Each system has its own unique module receiving information about engine speed and crankshaft/camshaft positions from the system sensors. The module monitors this information and passes it on to the PCM. A coil pack, with one ignition coil for every pair of firing-order-opposite cylinders, is mounted on and controlled by the module (Figure 11–29). The module on these systems performs the same function as an HEI module in a distributor-type ignition system,

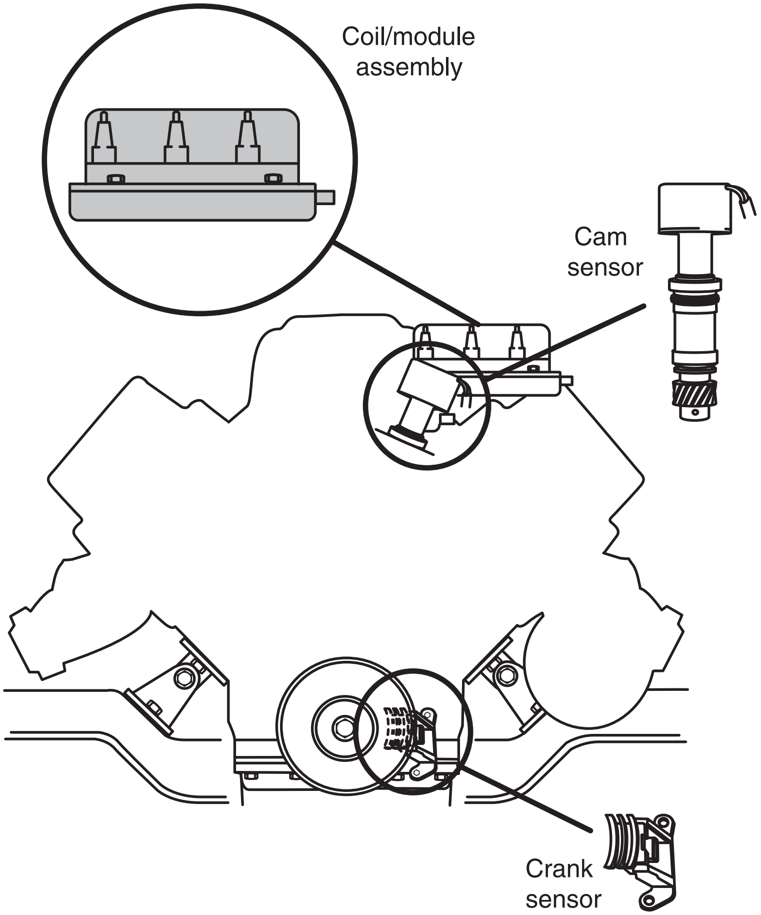


Figure 11–29 C3I system components.

with the same REF, bypass, EST, and ground circuits connecting the module to the PCM (Figure 11–30). In this case the module must select and fire each coil in the correct sequence. The module and coil pack may be mounted anywhere on the engine. The end of each coil's secondary winding is connected to a spark plug by way of a spark plug cable. A coil fires both of its spark plugs simultaneously each time the coil's primary circuit opens.

The spark plugs that the coil fires are in companion cylinders; those cylinders arrive at TDC at the same time but opposite each other in firing order. For instance, if the number-one cylinder is being fired at the end of its compression stroke (assume the firing order is 1-6-5-4-3-2), number 4 will be at the top of its exhaust stroke and will be fired also. It only takes about 2 to 3 kilovolts (kV) to fire a spark plug during the exhaust stroke, about the same additional voltage required to jump the rotor gap in a distributor.

The C3I system was introduced in 1984 on the 3.8-L turbocharged Buick engine. The C3I II system soon followed, and C3I III was introduced in 1988 on the 3800 (simply another name for the same displacement, but a new V6 engine, introduced that year). The ignition module is connected to the PCM by a 14-pin connector

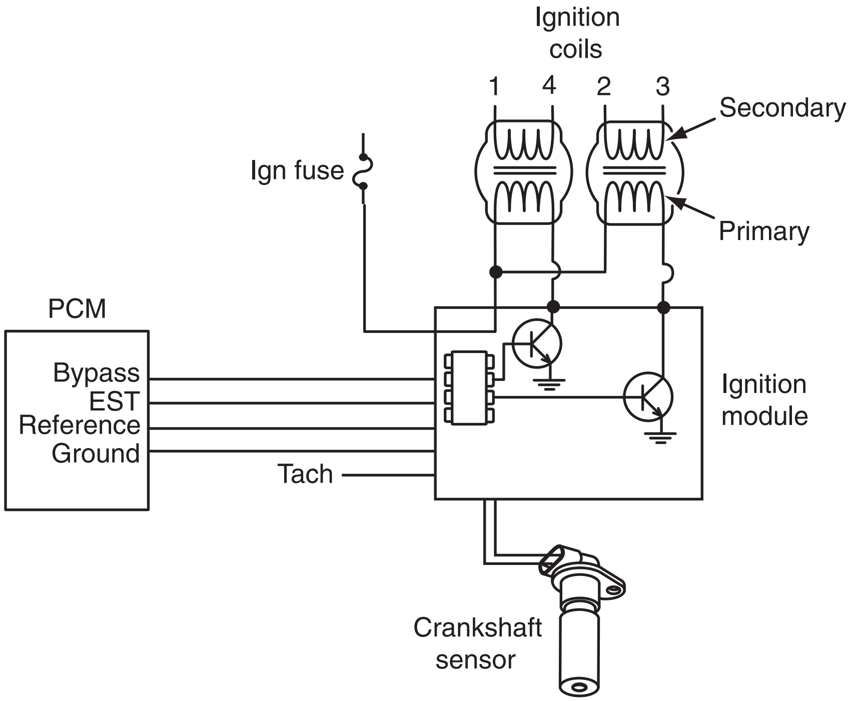


Figure 11–30 Four-cylinder DIS system schematic.

(Figure 11–31). Ignition switch voltage at terminal N powers the module; ignition switch voltage at terminal P powers the ignition coils. The PCM has a spark timing range capacity of 0 degrees to 70 degrees and will provide dwell times between 3 ms at high RPM and 15 ms at low RPM.

On Type I and Type II C3I systems and on DIS and IDI systems, the module has to see a signal from the cam or sync sensor during cranking before it knows what position the crank is in and which coil to fire. Thus, no spark occurs until the module sees the sync signal. Once that signal has occurred, the module knows what position the crankshaft is in and fires a coil for the next appropriate cylinder event signal, which is the second cylinder in the firing order. Depending on what position the crankshaft is in when cranking begins, the crankshaft may spin more than a full revolution before a spark occurs. On these systems the first cylinder to fire is always the second cylinder in the firing order. The C3I Type III (Fast Start) system provides slightly faster starting due to its improved sensor input.

IDI. This system is called *Integrated Direct Ignition* (IDI); it is used on the 2.3-L Oldsmobile Quad Four engine. The IDI system is similar to the Direct Ignition System. It uses the same crankshaft-mounted, seven-notch reluctor and crankcase-mounted magnetic sensor but a different module and harness connectors. No part of the IDI system is visible from the exterior of the engine. The coil, module, spark plugs, and wires are mounted under the topmost part of the engine, a cast engine cover (Figure 11–32).

Note that the Quad Four engine, like other four- and six-cylinder engines using either IDI or DIS systems, uses the same seven-notch reluctor on the crankshaft. Software hardwired into the module allows the system to make allowances for the correct number of cylinders.

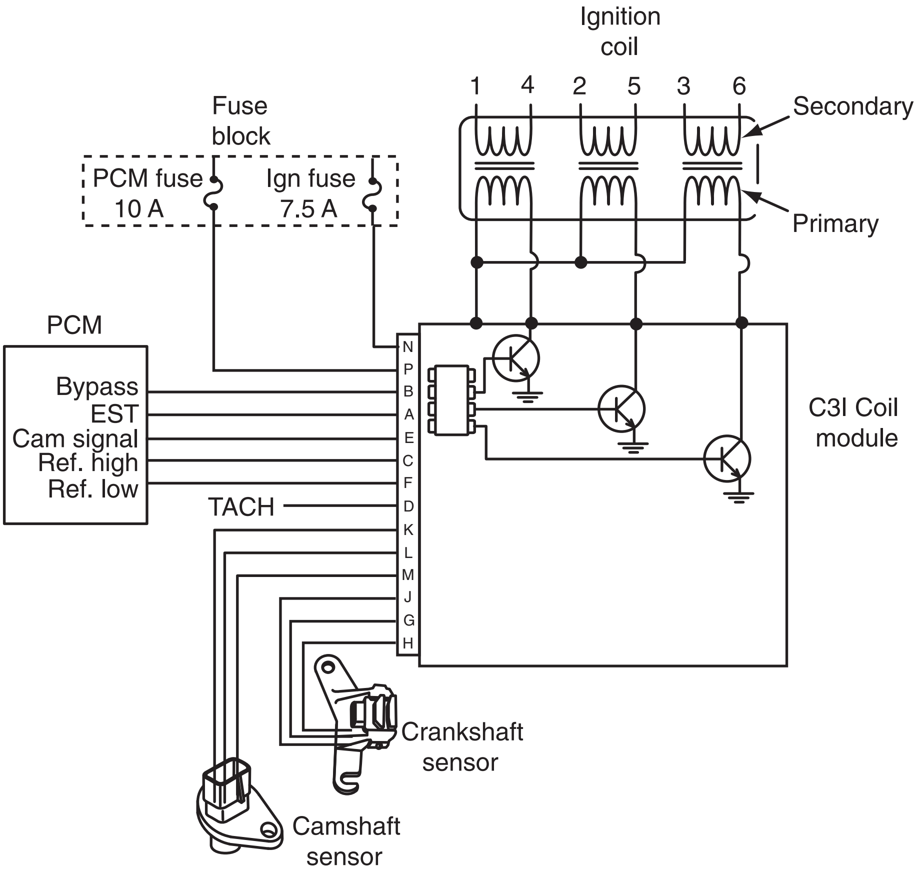


Figure 11–31 Wiring diagram for a C3I system turbocharged 3.8-L SFI V6 engine.

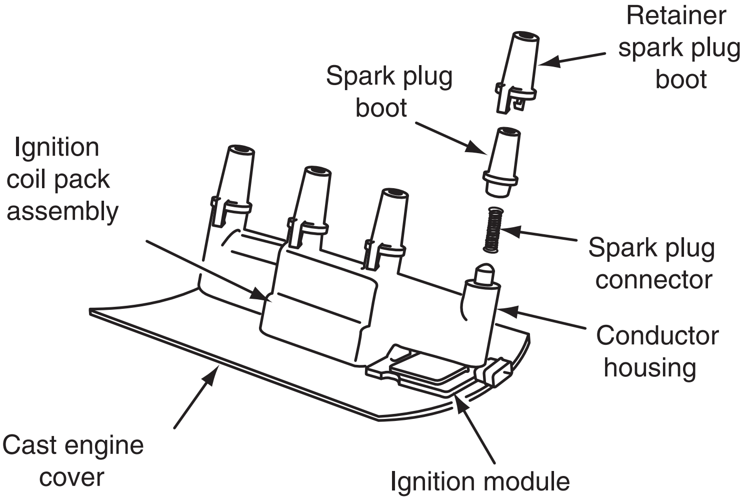


Figure 11–32 A Quad Four ignition system that does not use spark plug wires.

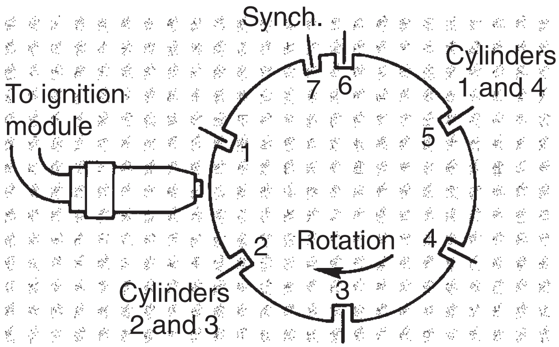


Figure 11–33 Four-cylinder coil firing sequence.

DIS. During *module mode* (see "Electronic Spark Timing" in Chapter 10) on four-cylinder applications, the signal produced by the sync notch tells the ignition module to skip the next signal (produced by the number 1 notch) and to fire the 2–3 coil on the signal produced by the number 2 notch (Figure 11–33). The module then skips the signals produced by notches 3 and 4 and fires the 1–4 coil in response to the signal produced by notch number 5. Notches 6 and 7 pass the sensor without the module responding to them, and the process begins again. Notice that the module is not concerned with cylinder firing order; it is concerned with coil firing order.

On the six-cylinder engine, the signal produced by notch number 7 instructs the ignition module to skip the signal from notch 1 and respond to the signal from notch number 2 to fire the 2–5 coil (Figure 11–34). The module then skips the signal from notch number 3 and fires the 3–6 coil on the signal from notch number 4. The signal from notch number 5 is skipped and the 1–4 coil is fired on the signal from notch number 6.

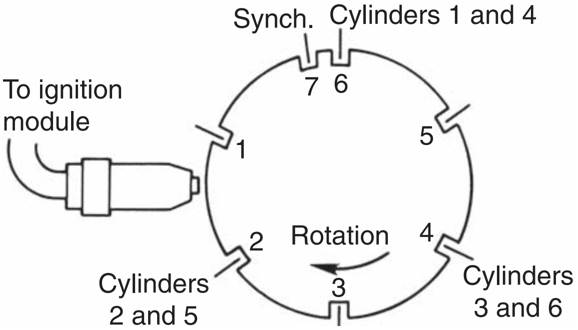


Figure 11–34 Six-cylinder coil-firing sequence.

Electronic Spark Control

All PFI systems except those on the 2.8-L engines are equipped with a subsystem to the EST system known as *Electronic Spark Control* (ESC). Its function is to retard ignition timing if detonation occurs. Since modern engines are designed to run at the ragged edge of knock, this requires precise controls. The ESC has its own hybrid module that works in conjunction with the PCM (Figure 11–35). Its operation is essentially the same as the later-style ESC system. The conditions under which ignition timing is retarded in response to spark knock are:

- engine speed above 1100 RPM
- ignition voltage to the PCM above 9 V
- no code 43 present

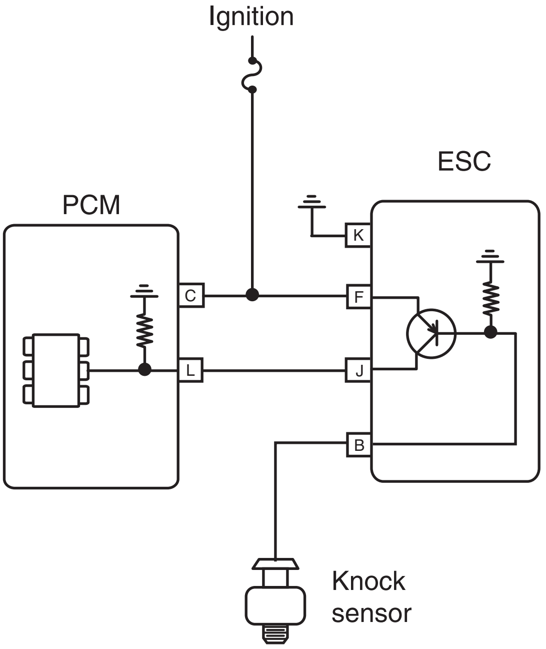


Figure 11–35 ESC circuit.

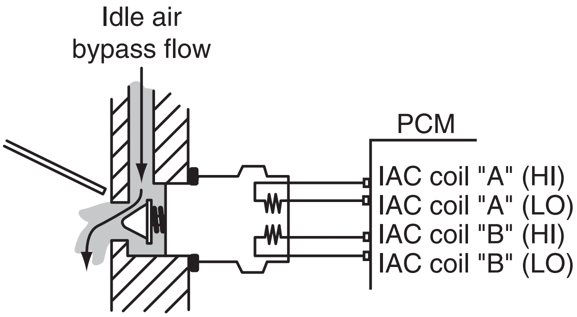


Figure 11–36 IAC motor control circuit.

Idle Air Control

The idle air control (IAC) assembly is a stepper motor and pintle valve, just as on the EFI system. It is screwed into the throttle body and controls idle speed (Figure 11–36). With one exception, it works like the IAC used on the EFI system. The exception is that the PCM references its count of the IAC's pintle valve position by moving the valve to its zero position (closed) each time the ignition is turned off, instead of when the PCM gets a 30 MPH signal from the VSS as the EFI system does. The PCM then issues a preprogrammed number of pulses to open the valve to a ready position for the next startup. The following inputs can affect idle speed performance:

- battery voltage
- coolant temperature
- throttle position
- vehicle speed
- mass air flow (MAF)
- engine speed
- A/C clutch signal
- power-steering pressure signal
- P/N switch signal

Air Injection Reaction System

Only some of the PFI systems require an air injection reaction (AIR) system.

2.8-L Engines. The 1985 2.8-L engine equipped with manual transmission uses an AIR system with a single-bed, three-way converter. During warm-up, the PCM energizes the air divert valve solenoid (Figure 11–37). The pump's air is then directed to the exhaust manifold. As the engine approaches normal temperature (and just before going into closed loop), the PCM turns off

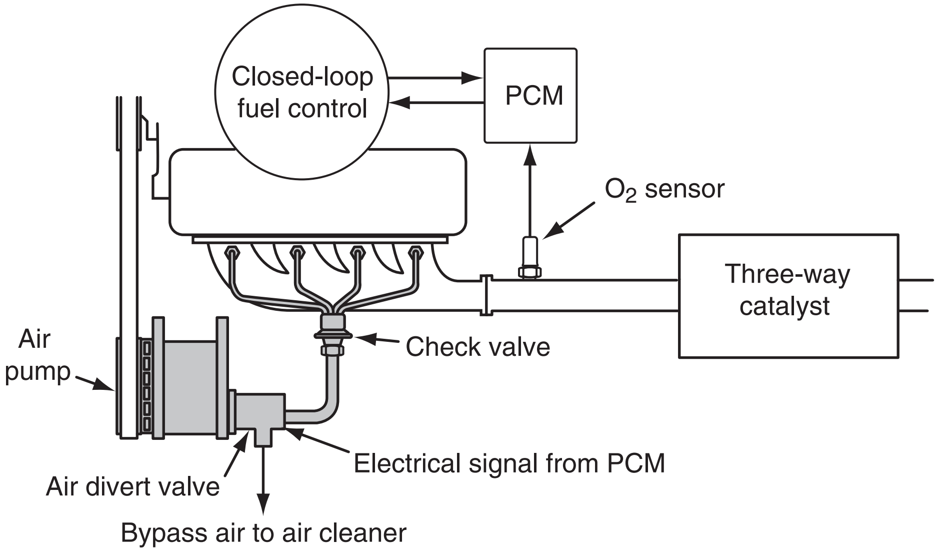


Figure 11–37 Air management system with single valve and catalyst.

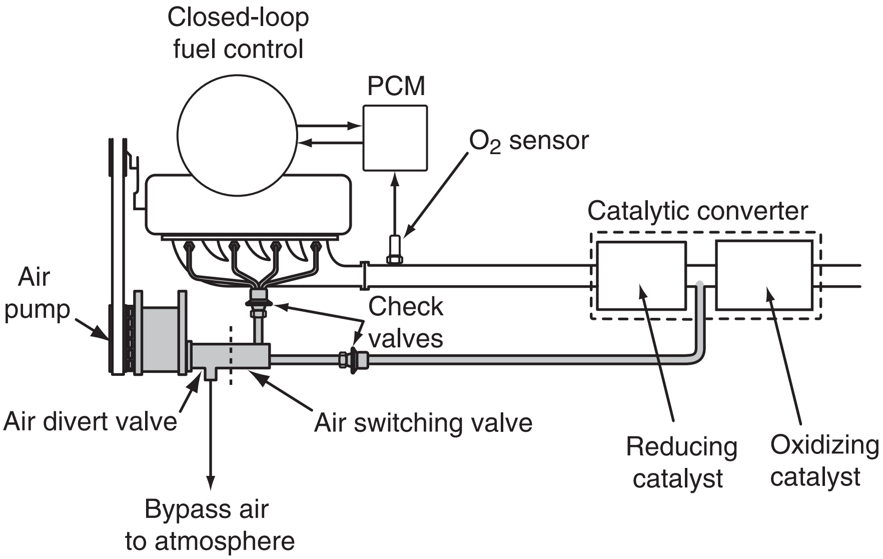


Figure 11–38 Air management system with dual valve and dual-bed catalyst used on 5.0-L and 5.7-L engines.

the solenoid. The air divert valve then directs the air to the air cleaner (divert mode).

5.0- and 5.7-L Engines. These engines use dual-bed, three-way catalytic converters. The air pump pumps air to the system combination valve; the combination valve, which contains two valves in one housing, directs air to any one of three places (Figure 11–38).

During engine warm-up, the PCM energizes the air divert, which then directs air to the air switching valve. The PCM also energizes the air switching valve, which then directs the air upstream to the exhaust manifold. As the engine approaches the temperature required to go into closed-loop operation, the PCM de-energizes the air switching valve, which then directs the air downstream to the second bed of the converter (the oxidation bed). If air were to continue to be pumped upstream to the exhaust manifold during closed-loop operation, the following would occur:

- This excess air ahead of the oxygen sensor would cause it to send the PCM a false lean signal, resulting in the PCM adjusting the air/fuel ratio far too rich.
- The resulting unburned hydrocarbons (HC) and carbon monoxide (CO) mixing with continued pumping of atmospheric air into the exhaust manifold would cause the temperature in the exhaust manifold to climb abnormally high.
- The atmospheric air pumped ahead of the NO_x reduction catalyst would convert CO to CO_2 before the CO could help the converter reduce the NO_x.

During WOT operation and deceleration, the PCM de-energizes the air divert valve so that it dumps the air from the pump to atmosphere. WOT is a rich air/fuel condition, and deceleration has the potential to go rich momentarily until the PCM leans out the fuel injectors' pulse width. With extra HC and CO making their way to the converter, additional air could cause the converter to overheat. Also, if the PCM senses a fault that results in illumination of the MIL and the potential for increased emissions, the air will be dumped to atmosphere as a precaution. Ultimately, the primary purpose of the air divert mode is to protect the catalytic converter from overheating.

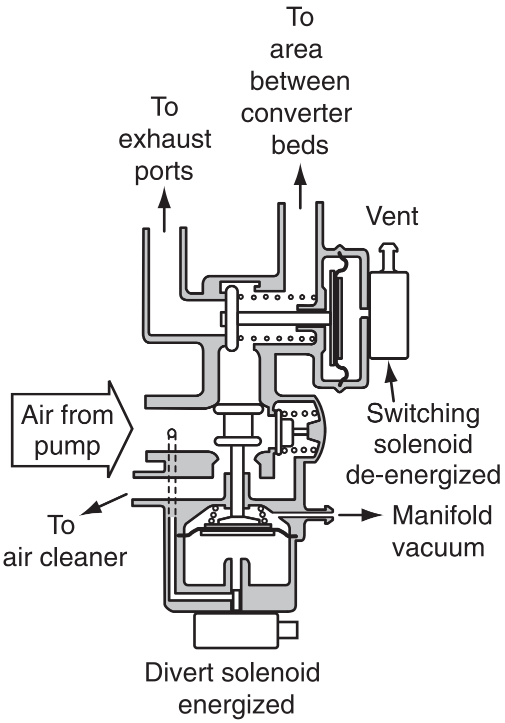

To exhaust ports
To area between converter beds
Vent
Air from pump
Switching solenoid de-energized
To air cleaner
Manifold vacuum
Divert solenoid energized

Figure 11–39 Divert mode (deceleration).

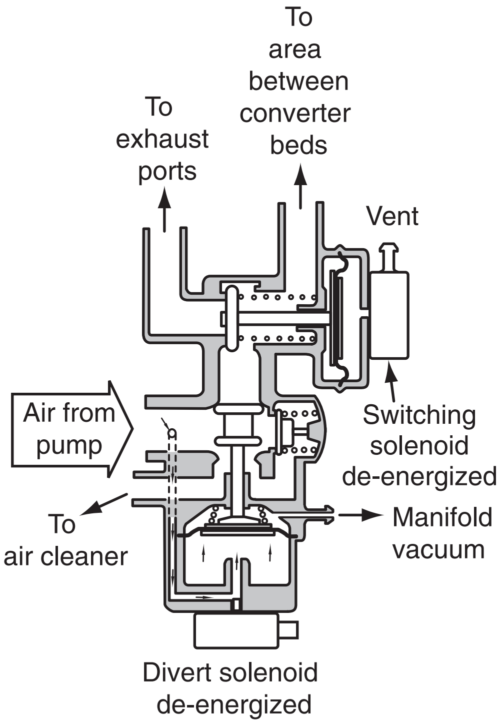

To exhaust ports
To area between converter beds
Vent
Air from pump
Switching solenoid de-energized
To air cleaner
Manifold vacuum
Divert solenoid de-energized

Figure 11–40 Divert mode (PCM commanded).

Air Management Valve Designs. Many different valve designs have been used on various C3 applications, so a discussion of each different valve is impractical. Most of them, however, are more alike than they are different. They all direct air flow by moving an internal valve to open or block a passage. The valves can be moved by a vacuum diaphragm, an electric solenoid, or a combination of the two. Figures 11–39, 11–40, 11–41, and 11–42 show a typical combination valve in different modes of operation.

In Figure 11–39 the vehicle is decelerating. The high vacuum signal has pulled the diaphragm of the divert valve (lower valve) up. The passage to the switching valve (upper valve) is blocked, and air is diverted to the air cleaner. The air cleaner serves as a pump silencer. Diverting the injection pump air to it has no effect on the air/fuel ratio since the injection air enters the intake air stream before any metering of air by the throttle.

In Figure 11–40 the PCM has put the air management system into divert mode by de-energizing the divert solenoid. This allows pump air pressure to be routed to the deceleration timing chamber. With the help of the manifold vacuum on the other side of the diaphragm, the pressure forces the diaphragm and divert valve up.

Figure 11–41 shows the air management valve directing air to the exhaust manifold during engine warm-up. Manifold vacuum is normally not strong enough to pull the divert valve diaphragm up, and the PCM keeps the divert solenoid energized, blocking pump air pressure from entering the deceleration timing chamber. The spring holds down the divert valve and allows air to flow up to the switching valve. The switching valve solenoid, energized by the PCM, allows a vacuum

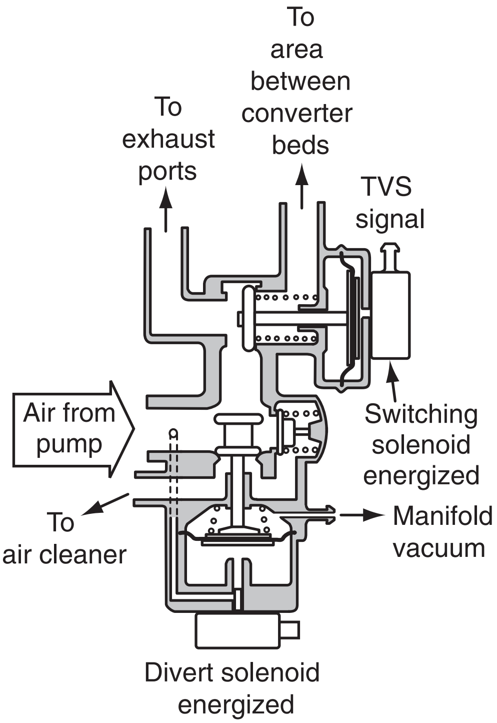

To exhaust ports
To area between converter beds
TVS signal
Air from pump
Switching solenoid energized
To air cleaner
Manifold vacuum
Divert solenoid energized

Figure 11–41 Air directed to exhaust manifold.

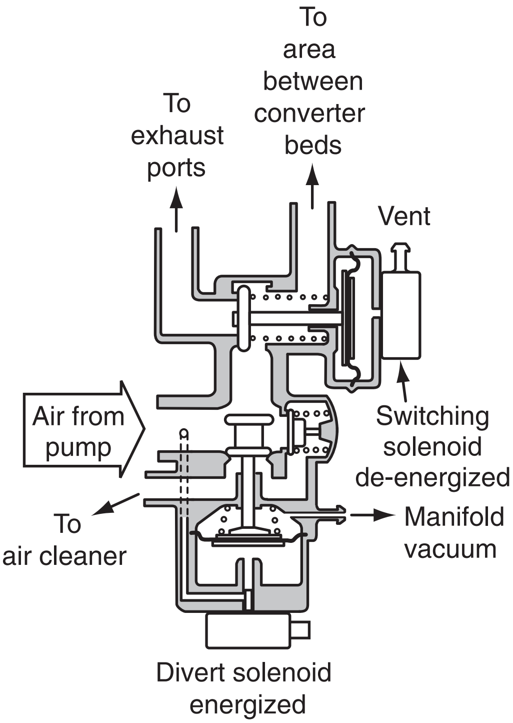

To exhaust ports
To area between converter beds
Vent
Air from pump
Switching solenoid de-energized
To air cleaner
Manifold vacuum
Divert solenoid energized

Figure 11–42 Warm engine mode (closed loop).

to apply to the upper diaphragm. This pulls it and the attached switching valve to the right to block the converter air passage, thus opening the exhaust port passage.

In Figure 11–42, the engine has warmed up and the C3 system is ready to go into closed loop. The PCM has de-energized the switching valve solenoid, which blocks vacuum to the diaphragm. The spring moves the valve to the left, opening the converter passage and blocking the exhaust port passage.

All air management valves used with C3/PFI systems use a pressure relief valve. At high engine speeds, the pressure relief valve exhausts excess air to reduce system pressure. This can easily be mistaken for a divert mode function.

Pulsair System. Some vehicles, especially those with four-cylinder engines, use a **Pulsair system** instead of an air injection system. Between exhaust pulses in the exhaust manifold, a low-pressure pulse develops. This low pressure can be used to siphon air into the exhaust ports. This air is drawn through a tube with a check valve (usually a reed-type flap). The check valve blocks reverse air flow during the exhaust pulse.

Pulsair Shutoff Valve. When a Pulsair system is combined with the C3 system, the PCM uses a Pulsair shutoff valve to control air flowing into the exhaust system (Figure 11–43).

During engine warm-up, the solenoid is energized and a vacuum is applied to the diaphragm. The valve is pulled down and air is allowed to flow into the exhaust system. With the exception of how air is made to flow, this system is very similar to the single-valve air management system.

Exhaust Gas Recirculation

The exhaust gas recirculation (EGR) valve lets small amounts of inert exhaust gas into the

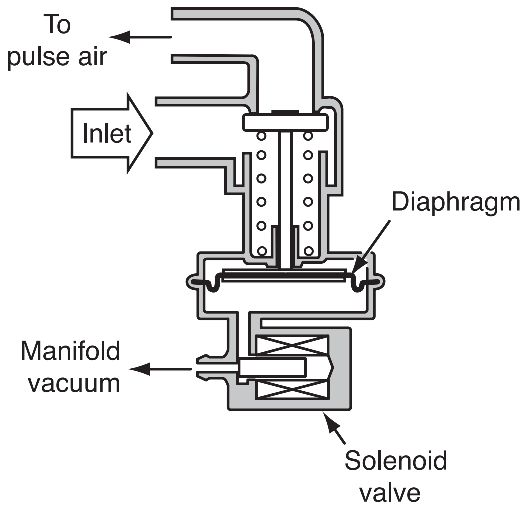


Figure 11–43 Pulsair shutoff valve.

intake manifold to lower combustion temperature by slowing combustion, thereby reducing the production of oxides of nitrogen (NO_x). The EGR valve is opened by ported vacuum (manifold vacuum on some applications), which pulls the diaphragm up against the diaphragm spring (Figure 11–44). Three types of vacuum-operated EGR valves are used: the standard ported valve as shown in Figure 11–44, a positive back-pressure valve, and a negative back-pressure valve. The latter two valves are very similar in design to the standard valve, except that they are sensitive to and modulated by exhaust back pressure or a combination of exhaust back pressure and manifold vacuum, respectively. They can be identified by:

- a “P” stamped on the top of the positive back-pressure valve (Figure 11–45)
- an “N” stamped on the top of the negative back-pressure valve
- a blank space on top of the port valve

Whatever valve is used, vacuum to it is controlled by a vacuum control assembly (Figure 11–46). The control assembly solenoid is pulsed many times per second by the PCM. When the solenoid is turned on, vacuum to the EGR port is blocked. The strength of the vacuum signal, which controls how far the EGR valve opens, is controlled by varying the pulse width. The solenoid is fitted with a vent filter that must be replaced periodically. The PCM controls the solenoid using input concerning coolant temperature,

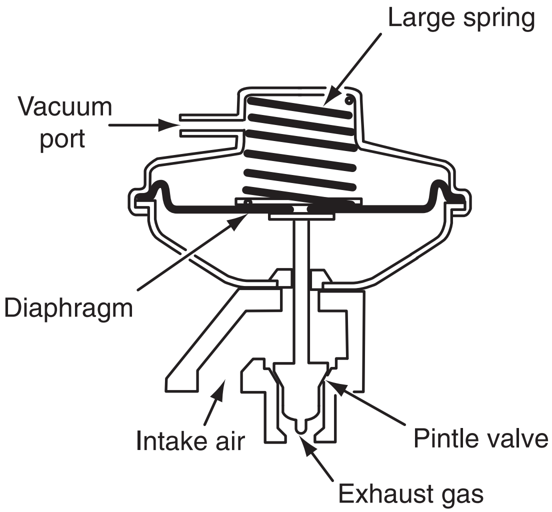


Figure 11–44 Typical design of an EGR valve.

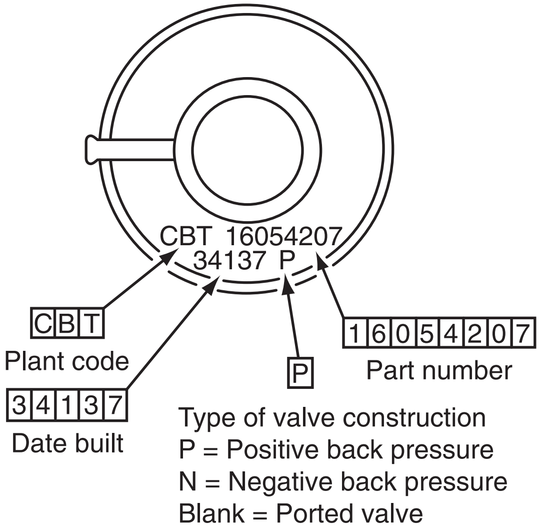


Figure 11–45 EGR valve identification.

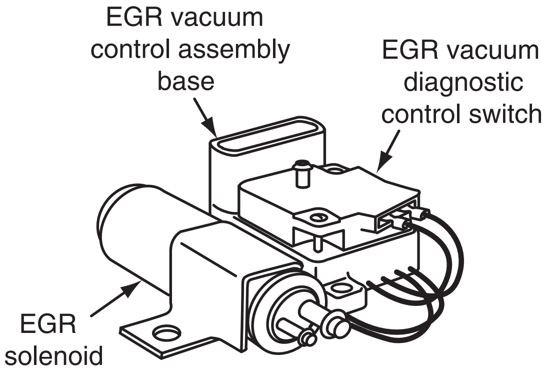

EGR vacuum control assembly base
EGR vacuum diagnostic control switch
EGR solenoid

Figure 11–46 EGR vacuum control assembly.

throttle position, and MAF. The EGR valve is not opened unless the engine is warm and above idle.

Integrated EGR Valve. In 1987, GM introduced an integrated EGR valve on the 2.8-L V6 (Figure 11–47). This valve is vacuum-operated by a ported vacuum signal. It contains two additional components: a normally closed vent solenoid and a potentiometer. If the PCM leaves the solenoid de-energized, ported vacuum controls the EGR valve. If the PCM wishes to interfere with this control, it energizes the solenoid, opening the vent. The potentiometer is used by the PCM to monitor the position of the EGR pintle, similar to the EGR valve position sensors that Ford introduced in 1980 on its EEC systems. The GM valve also includes a replaceable filter on the vent solenoid. If it is determined that a fault exists with either the vent solenoid or the potentiometer, the entire assembly must be replaced. The integrated EGR valve is easily recognized by a group of five wires connected to the valve (two to control the solenoid and three for the potentiometer).

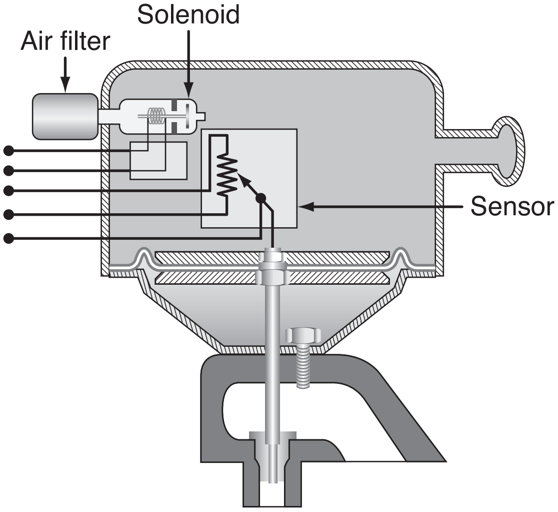


Figure 11–47 Cross section view of an integrated EGR valve.

Digital EGR Valve. A new concept in EGR valves is employed on the 3800 V6 engine for 1988 and beyond. The digital EGR valve provides the following advantages:

- vacuum is not required for its operation
- increased control of EGR flow
- faster response to PCM commands
- greater PCM diagnostic capability

The digital EGR valve is directly operated by solenoids rather than by a vacuum diaphragm. Instead of trying to regulate EGR flow by controlling how far the valve opens or by duty cycling it, three different valves are used to open or close three different-size orifices. Each valve can be opened or closed independently of the others, allowing any of seven different increments of exhaust gas flow into the induction system (Figure 11–48). Orifice number 1, when open, flows 14 percent of the maximum EGR flow. Orifice number 2, when open, flows 29 percent of the maximum flow. Number 3 flows 57 percent of maximum flow when open. By manipulating which valve or combination of valves is open at any given time, EGR flow can be easily and accurately controlled.

The digital EGR assembly consists of the EGR base, the EGR base plate, and the solenoid and mounting plate assembly (Figure 11–49). When the base and base plate are fitted together, there is a sealed cavity between them, with the base forming the floor of the cavity and the base plate forming the ceiling of the cavity. There are four holes in the base (floor). The center hole is

Increment	Orifice #1 (14%)	Orifice #2 (29%)	Orifice #3 (57%)	EGR flow (%)
0	closed	closed	closed	0
1	open	closed	closed	14
2	closed	open	closed	29
3	open	open	closed	43
4	closed	closed	open	57
5	open	closed	open	71
6	closed	open	open	86
7	open	open	open	100

Figure 11–48 Increments of EGR flow with digital EGR valve.

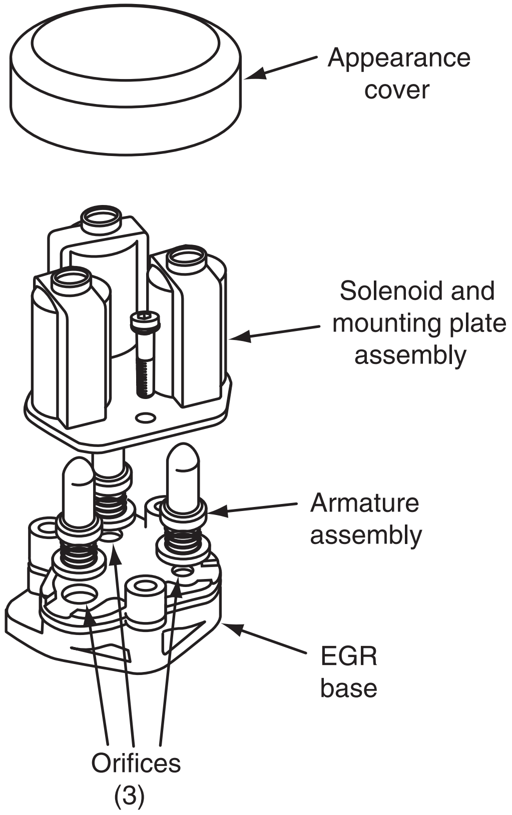


Figure 11–49 A digital EGR valve with three solenoids.

always open, allowing exhaust gas to enter the cavity. The other three holes are closed by the three EGR valve pintles. The pintles are attached to their pintle shafts by a ball-joint type of connection so they can more readily align with the seats they rest on and maintain a more positive seal.

The pintle and its shaft are part of the armature assembly. Each pintle–shaft–armature assembly is held down by its armature return spring, which is attached to the lower portion of the shaft. When one of the solenoid windings in the solenoid assembly is turned on by the PCM, the resulting magnetic field lifts the corresponding armature assembly. This opens the valve and compresses the return spring. When the PCM turns the solenoid off, the spring drives the armature assembly back down and closes the valve.

Some engines use a two-solenoid digital EGR valve, which works the same way except that it only has three different EGR flow rates. When the first valve is open, about 33 percent of the total EGR will flow. When the second valve is open, about 66 percent of the total will flow. When both valves are open, 100 percent of EGR flows.

By not relying on vacuum to operate the EGR valve assembly, the PCM can be made to monitor EGR system operation for fault diagnosis without any additional external hardware. If a

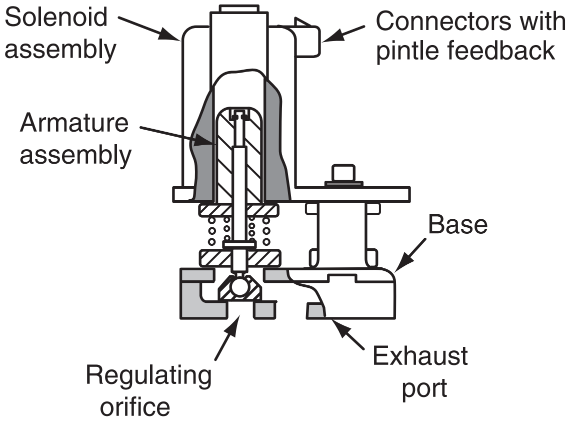


Figure 11–50 Linear EGR valve design.

short or open occurs in any one of the solenoid circuits, a code will be set in the PCM's keep-alive memory (KAM). Each solenoid has its own assigned DTC.

Linear EGR Valve. In 1994, GM introduced the linear EGR valve (Figure 11–50). This valve, like the digital EGR valve, controls exhaust gas recirculation directly without the use of vacuum as a control medium. The linear EGR valve uses a single, normally closed, solenoid-operated pintle valve operated by the PCM using a pulse-width modulated signal to control the volume of exhaust gasses allowed to re-circulate into the intake manifold. The movement of the pintle is monitored by a potentiometer, which produces a feedback signal for the PCM, ranging between about 1 V when the valve is closed to about 4.5 V when the valve is open.

Charcoal Canister Purge

The PCM operates a solenoid that controls vacuum to the purge valve on the charcoal canister (Figure 11–51). The solenoid is turned on, blocking vacuum to the purge valve when the engine is cold or at idle. The PCM turns off the solenoid and thus allows any stored hydrocarbons (fuel) to be purged through the purge valve when:

- The engine is warm.
- The engine has run for a preprogrammed amount of time since it was started.
- A preprogrammed road speed is reached.
- A preprogrammed throttle opening is achieved.

In addition to the purge valve, some engine application canisters also have a non–PCM-controlled control valve that is controlled by

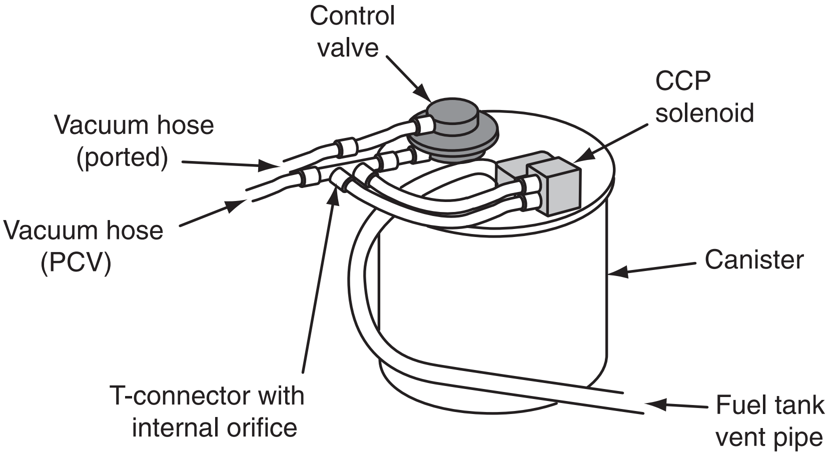


Figure 11–51 Charcoal canister.

ported vacuum. When vacuum is applied to it, it allows canister purging to occur through another port connected to manifold vacuum.

For 1987, the Chevrolet 5.0- and 5.7-L engines have a revised canister purge strategy. When the engine is operating in closed-loop mode, the PCM will duty cycle the purge solenoid to control the amount of vapor admitted into the engine's induction system, rather than just turning the purge solenoid on to stop purging and off to allow purging. The PCM uses input from the oxygen sensor to determine the volume of vapor to purge from the canister. If a rich condition is indicated by the oxygen sensor, purge volume is reduced. This strategy is intended to provide improved driveability.

Turbocharger

The major factor that determines engine power is the quantity of air and fuel that is delivered to the cylinders. Putting more fuel in is a fairly simple matter. Putting more air in is not so simple (the proper air/fuel ratio must be maintained). The amount of air that can be put into the cylinder is limited by atmospheric pressure unless some means is used to force air in at greater than atmospheric pressure. This is accomplished with some type of supercharger, the turbocharger being the most popular and generally the most efficient.

A turbocharger is a centrifugal, variable-displacement air pump driven by otherwise wasted heat energy in the exhaust stream. It pumps air into the intake manifold at pressures that are limited only by the pressure that can be developed without significantly increasing the air's temperature.

Most **normally aspirated** engines (those that rely on atmospheric pressure to fill the cylinder) only fill the cylinder to about 85 percent of atmospheric pressure (they actually achieve 85 percent volumetric efficiency [VE] at full throttle with the engine at its maximum torque speed). Turbocharging produces VE values in excess of 100 percent.

Turbocharger Operation. After leaving the manifold, the hot exhaust gasses flow through the vanes of the exhaust turbine wheel and thus spin it (Figure 11–52). As the engine's production of exhaust increases, the faster the turbine spins. It can achieve speeds in excess of 130,000 RPM. The exhaust turbine drives a short shaft that drives a compressor turbine. The high speed produces centrifugal force to move the air from between the vanes and thus causes it to flow out in a radial fashion. The air is then channeled into the intake manifold. As air is thrown from the turbine vanes, a low pressure develops in its place. Atmospheric pressure pushes more air through the air cleaner, the MAF sensor (if used), and the throttle body.

A criterion turbine speed must be reached before a pressure boost is realized; this speed varies with turbine size and turbocharger design. If turbine speed goes too high, boost pressure (and charge temperature) will also go too high and can cause pre-ignition and engine damage. To limit boost pressure, a **wastegate** is used to divert exhaust gasses away from the exhaust turbine and thus limit its speed.

Wastegate. The wastegate opens by a wastegate actuator. A spring in the actuator holds the wastegate closed. When manifold pressure (turbo boost) reaches approximately 8 psi, it overcomes the actuator spring and opens the wastegate. If, however, engine operating parameters are favorable (coolant temperature or incoming air temperature, for example), the PCM pulses a wastegate solenoid, which in turn bleeds off some of the pressure acting on the actuator. When this occurs, boost pressure is allowed to rise to 10 psi before the wastegate opens.

A code 31 is set if:

- An over-boost is sensed by the MAP sensor on the 1.8-L engine.
- The PCM, monitoring the wastegate solenoid circuit operation, sees a malfunction in the circuit while the solenoid is operated between a 5 percent and a 95 percent duty cycle on the 3.8-L engine.

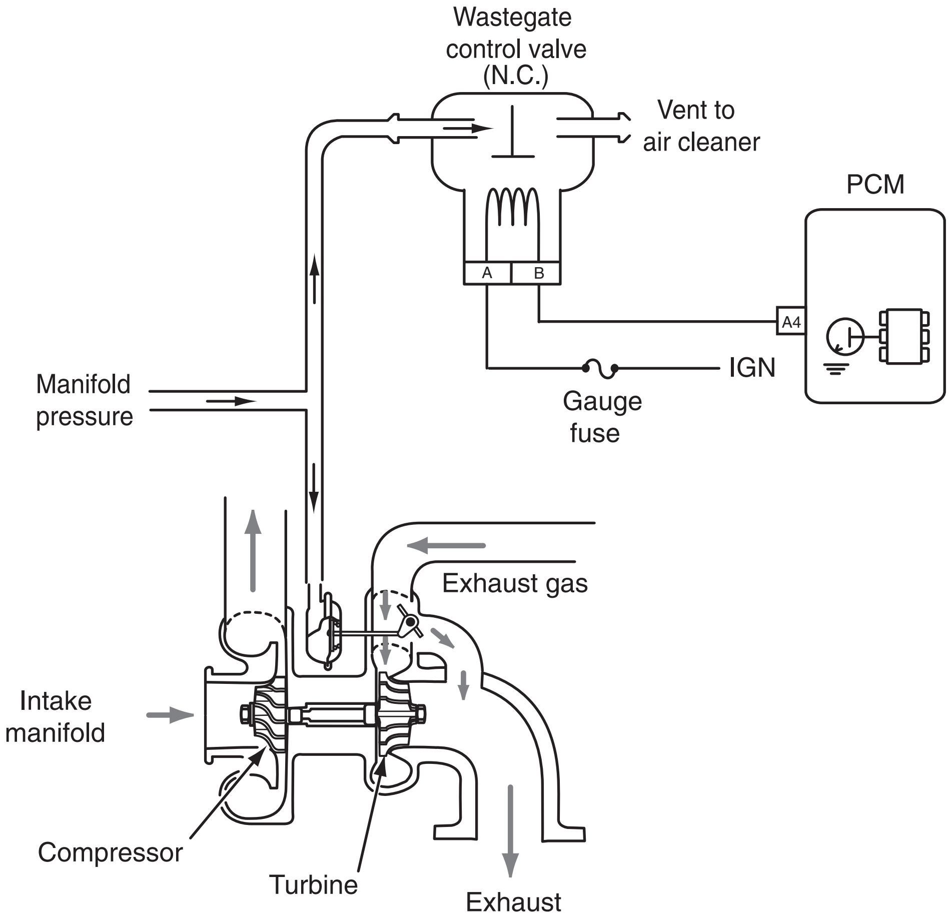


Figure 11–52 Turbocharger and wastegate control (typical).

Transmission Converter Clutch

Notice that the name has changed slightly from this unit's application on the EFI system, in which "TCC" meant "torque converter clutch." With this system it is referred to as the *transmission converter clutch.* It is still the same part, however. The purpose of the TCC is still to increase fuel economy. It does so by eliminating hydraulic slippage during cruise conditions and by eliminating heat production in the torque converter, especially during overdrive operation. For additional information on TCC operation, see Chapter 10.

Electric Cooling Fan

All General Motors vehicles with transverse-mounted engines and a few with **longitudinal** engines (parallel to the center line of the car) are equipped with an electric cooling fan to pull air through the radiator and A/C condenser. Control of the fan varies somewhat with engine application. In all cases, however, the fan is turned on when:

- Coolant temperature exceeds a specified value. This is done by either the PCM or a coolant temperature override switch on

Turbochargers

Because a turbocharger puts more air into the cylinder, it raises the engine's compression pressure. Because it does not produce significant boost pressure at low exhaust flow rates, it allows an engine the benefits of low compression during light throttle operation and high compression during heavy throttle operation. Low compression offers lower combustion chamber temperatures, which result in less wear and lower NO_x emissions. High compression provides higher combustion chamber temperatures, which result in more complete combustion and more power for the amount of fuel consumed.

Another way to look at it is in terms of displacement. If an engine is operating at an atmospheric pressure of 14 psi, and the turbocharger is producing a boost of another 14 psi, the cylinders are charged at a pressure of 28 psi. The engine is consuming approximately twice the amount of air it could without the turbocharger. We have effectively doubled the engine's displacement. The engine certainly does consume twice as much fuel, too, but not as much as it would with twice the displacement, because the higher compression pressure and temperature produce more complete combustion. The turbocharged engine also weighs less than an equivalently powerful naturally aspirated engine, thus saving on the amount of work done.

some applications, and by the PCM only on others.

- A/C compressor output pressure (head pressure) exceeds a specified value. This is done by a switch in the high-pressure side of the A/C system on some engine applications. It is done by the PCM on other applications (on these applications, an A/C head pressure switch feeds head pressure information to the PCM).

On most applications, the PCM turns on the fan any time the A/C is on and vehicle speed is less than a specified value. Others turn it on under a specified speed whether the A/C is on or off. Once the vehicle reaches a criterion speed, enough air is pushed through the radiator without the aid of the fan, unless overheating or high A/C head pressure conditions exist. This is a fuel economy feature. Study Figure 11–53 as a typical example.

Air-Conditioning (A/C) Control

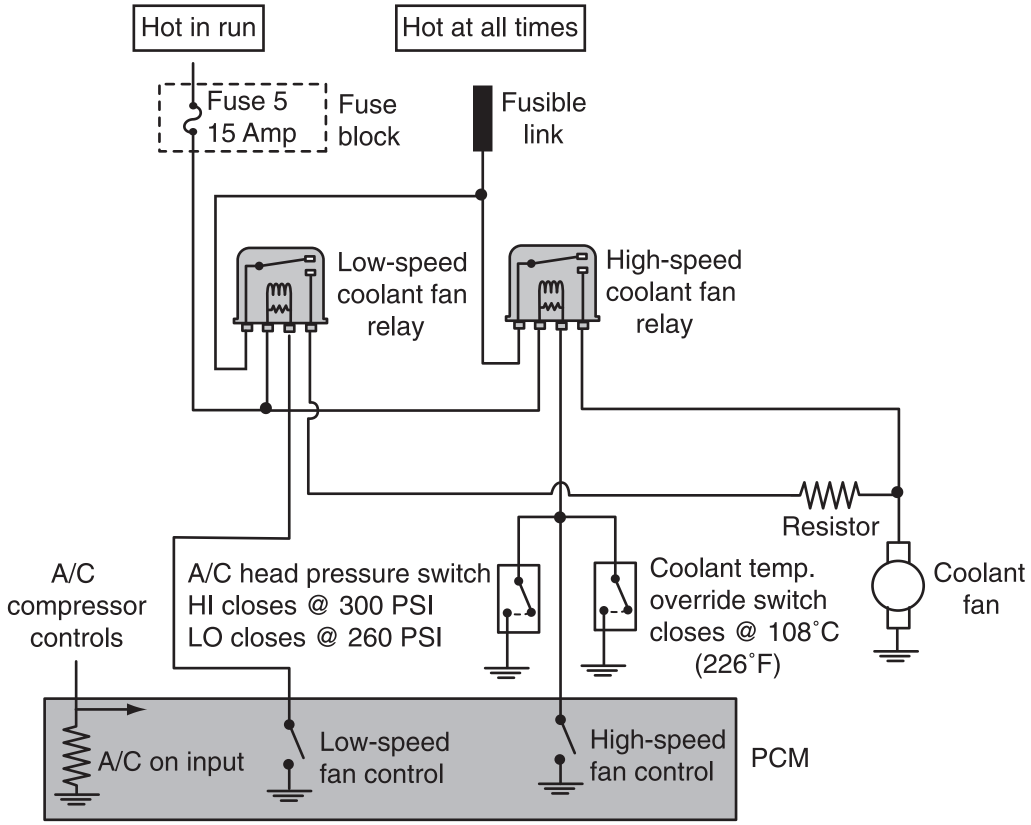
The PCM controls the relay that turns the A/C clutch on and off for two and in some cases three reasons:

1. When the A/C control switch (on the instrument panel) is turned on, the PCM delays A/C clutch engagement for 0.4 second to allow time to adjust the IAC valve.
2. The PCM disengages the A/C clutch during WOT operation.
3. On some applications, the PCM turns off the A/C clutch if power steering (P/S) pressure exceeds a specified value during idle. On others the P/S switch is in series with either the A/C clutch or the winding of the A/C relay and disengages the A/C clutch without relying on the PCM.

✔ SYSTEM DIAGNOSIS AND SERVICE

Self-Diagnosis

The self-diagnostic capacities and procedures of the PFI systems are essentially the same as those of the C3/EFI system discussed in the "System Diagnosis and Service" section of Chapter 10. In 1988 General Motors made a significant increase in the self-diagnostic capability of most PFI engine applications. The PCM was designed to monitor more circuits, both input and output. New DTCs were also assigned. It is important to note that from year to year, and in some cases even from engine to engine within a single model year, DTCs may have different



COOLANT FAN CONTROL OPERATING CONDITIONS

A/C sw.	Head press.	Road speed	Eng. temp.	Fan speed	Fan on because
Off/On	Under 260 PSI	Under 45 MPH	Over 98˚C	Low	PCM turned on
Off/On	Under 260 PSI	Under 45 MPH	Under 95˚C	Off	
Off/On	Under 260 PSI	Over 45 MPH	Under 106˚C	Off	
On	Over 260˚C	N/A	N/A	Low	A/C head sw. (Low)
On	Over 300˚C	N/A	N/A	High	A/C head sw. (High)
Off/On	N/A	N/A	Over 106˚C	High	Coolant temp. override sw.
Without A/C					
Ign. sw.		Road speed	Eng. temp.	Fan speed	Fan on because
On		N/A	Over 98˚C	Low	PCM turned on
On		Over 45 MPH	Under 108˚C	Off	
On		Over 45 MPH	Over 108˚C	High	Coolant temp. override sw.

Figure 11–53 Coolant fan control circuit (typical).

meanings. Be sure the service literature you use is applicable to the engine being serviced and to the model year of the vehicle.

TCC Test Lead. The TCC test lead is in cavity F of the diagnostic link connector (DLC). It can be used to monitor the TCC circuit operation with a voltmeter or test light or it can be used to ground the TCC test lead, overriding the PCM.

Fuel Pump Test Lead. On some vehicles, the fuel pump test lead is found in cavity G of the DLC. On others, it is found on the left side of the engine compartment. A voltmeter or test light can be connected to this lead to determine whether the fuel pump relay or oil pressure switch has supplied power to the fuel pump power lead. Alternatively, a jumper wire can be connected from the test lead to a 12-V source. This powers the fuel pump for fuel pressure or injector tests.

WARNING: When powering the fuel pump with a jumper wire, be sure that there are no fuel leaks and avoid causing any sparks. Otherwise there is a serious fire hazard.

Diagnostic Procedure

Diagnostic Circuit Check. After making a thorough visual inspection, paying particular attention to possible causes of vacuum leaks and correcting any problems found, perform the diagnostic circuit check. This procedure is outlined in the service manual. It is designed to identify the type of problem causing the complaint, and it refers the technician to the next step or chart to use.

Fuel Pressure Test. Some diagnostic charts call for a fuel pressure test. Fuel pressure is critical to the performance of a fuel injection system. The fuel rail has a fuel pressure test fitting that contains a Schrader valve like that used in an A/C pressure test fitting or in the valve stem of a tire.

WARNING: While the fuel pressure gauge hose is screwed to the test fitting, a shop towel should be wrapped around the fitting to prevent gasoline from being sprayed on the engine. Remember, the fuel is under high pressure and the residual check valve in the fuel pump can hold pressure for some time after the engine is shut off. Spraying fuel can be not only a fire danger but also a risk to the eyes and nose. Be sure to wear your safety glasses when performing any fuel system work.

Injector Balance Test

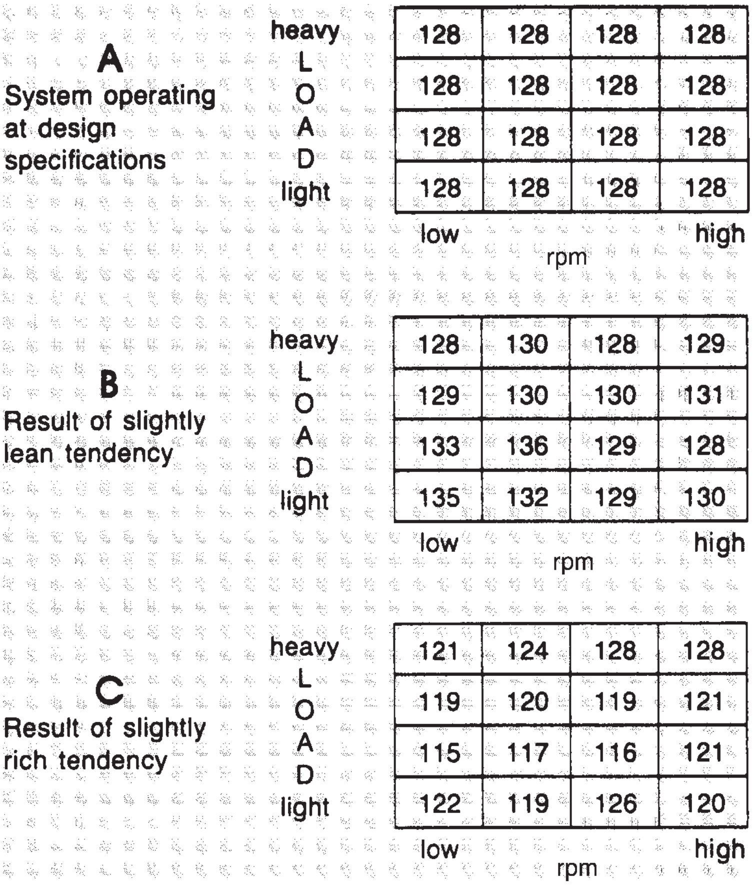
To realize some of the advantages of PFI, the injectors must all deliver the same amount of fuel to each cylinder. The injector balance test tests injector performance and uniform fuel delivery. Check the applicable service manual for specific directions.

Fuel Trim

Fuel trim is a function programmed into the PCM on fuel-injected applications; it is designed to affect the PCM's control of the air/fuel ratio and to allow the PCM to adjust the fuel injector's pulse width to compensate for the wear and aging of components as they affect air/fuel ratios. This is similar to the manner in which a PCM on a feedback-carbureted system is able to adjust the duty cycle to maintain a stoichiometric air/fuel ratio.

Fuel trim is divided into two parts: *short-term fuel trim* (STFT), and *long-term fuel trim* (LTFT). Prior to the OBD II standardization of terms and acronyms, GM referred to LTFT as **Block Learn** and STFT as **Integrator.** STFT is the immediate reaction to the oxygen sensor. LTFT is an adjustment designed to keep the oxygen sensor averaging the ideal 450 millivolts (mV). Most applications today allow the technician to look at both of these on a scan tool to aid in diagnostics. Therefore, it is important that the technician be able to understand how these functions affect the PCM's control of air/fuel ratio.

Both fuel trims consist of electronic look-up tables (electronic charts) in the PCM's memory chip known as RAM (the only memory chip into which



A
System operating at design specifications

LOAD				
heavy	128	128	128	128
	128	128	128	128
	128	128	128	128
light	128	128	128	128
	low	rpm		high

B
Result of slightly lean tendency

LOAD				
heavy	128	130	128	129
	129	130	130	131
	133	136	129	128
light	135	132	129	130
	low	rpm		high

C
Result of slightly rich tendency

LOAD				
heavy	121	124	128	128
	119	120	119	121
	115	117	116	121
light	122	119	126	120
	low	rpm		high

Figure 11–54 Block learn information.

the microprocessor can record information). These look-up tables are divided into 16 cells (or blocks) spread across the possible combinations of engine load and RPM (Figure 11–54). Prior to OBD II standardization, GM used the number 128 as the neutral number. This is the middle value of the numeric range available to an 8-bit computer—0 through 255. (See Chapter 2 for further information on this.) When the number in a cell is 128, the base fuel calculation will not be modified. If the oxygen sensor reports that a lean condition exists, the microprocessor (central processing unit [CPU]) records this information in the fuel trim by increasing the value in the cell. If the oxygen sensor reports that a rich condition exists, the CPU records this information in the fuel trim by decreasing the value in the cell. When the CPU is again ready to energize a fuel injector, it looks at the fuel trim numbers. Numbers higher than the neutral number tell the CPU that it must add fuel to the base fuel calculation by increasing injector on-time; numbers lower than the neutral number tell the CPU that it needs to subtract fuel from the base fuel calculation by decreasing injector on-time. Note the results of slightly lean tendencies and slightly rich tendencies of the engine in Figure 11–54. To find where the rich or lean tendencies are, a technician can retrieve this information with a scan tool. Under the standardization of OBD II, all manufacturers now use the whole number one as the neutral number. The advantage of this is that a scan tool now shows the fuel that the PCM has learned to add or subtract as a *percentage* of the base fuel calculation, making it easier for a technician to interpret the severity of a problem. See Chapter 4 for additional information on fuel trim.

PCM, PROM, and CALPAK Service

If correctly used diagnostic procedures call for a PCM to be replaced, check the PCM and PROM service and part numbers to be sure they are the right units for the vehicle. If a PROM is replaced, check that it has not been superseded by an updated replacement PROM. This can be done with the aid of the dealer's parts department or with service bulletins. Some aftermarket service manuals contain service bulletins. Carefully remove the PROM and CALPAK from the PCM to be replaced. The service (replacement) PCM does not include a new PROM or CALPAK. Be careful not to touch the pins of either unit with your fingers because static electricity applied to the pins can damage them. Store them in a safe place while they are out of the PCM.

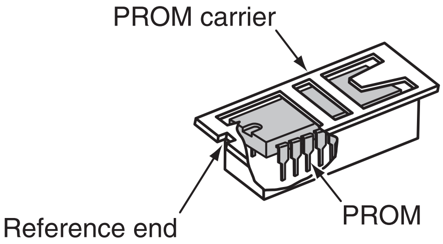


Figure 11–55 PROM and PROM carrier.

When the PROM is reinstalled, be sure to orient it properly to the PROM carrier (Figure 11–55). If it were to be inserted incorrectly, it would be damaged when the PCM is powered up again.

Weather-Pack Connectors

All PFI system harness connections under the hood are made with weather-pack connectors.

Diagnostic & Service Tips

IAC Assembly

If the engine is run with the IAC harness disconnected or if the IAC assembly is removed and reinstalled, idle speed will probably be incorrect when it is reconnected. To re-reference idle speed, simply start the engine with the IAC harness connected. Allow the engine to warm up, and then turn off the ignition. The 3.0- and 3.8-L engines re-reference simply by cycling the ignition on and off.

If the IAC assembly is removed, be sure that the distance from the tip of the pintle valve to the motor housing does not exceed 28 mm ($1\frac{1}{8}$ in.) (Figure 11–56). Otherwise it will be damaged when it is installed. See the service manual for detailed instructions.

When the assembly is installed, use the correct torque specifications. Over-tightening of the IAC can distort the IAC housing and cause the motor to stick. Complaints of engine stalling as the vehicle comes to a stop can be a

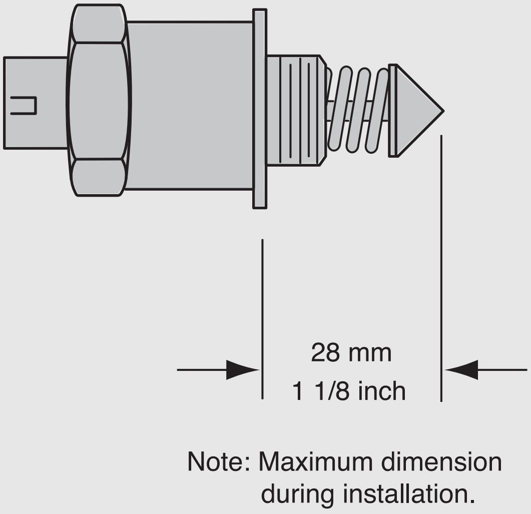


Figure 11–56 IAC motor.

result of this condition. Also, if the IAC assembly is replaced, be sure to get the right part. There are three different pintle shapes, and the correct one must be used.

Minimum Idle Speed Adjustment

Minimum idle speed is the speed achieved when the IAC valve is in its closed position. The only air getting into the intake manifold is what goes by the throttle blade (unless there is a vacuum leak). An idle stop screw is used to position the throttle blade. The head of the idle stop screw is recessed and covered with a metal plug. The plug can be removed and the idle stop screw adjusted. However, this should only be done if the throttle body is replaced or a service procedure calls for it. This is not a normal service routine adjustment.

To set the minimum idle speed adjustment, the engine should be warm and the IAC valve fully extended (closed). Consult the appropriate service manual for specific directions and specifications.

TPS Adjustment

The TPS on some PFI systems is adjustable. Adjustment is checked by connecting a voltmeter between terminals A and B at the sensor connection with the ignition on. The technician can access the terminals for testing by disconnecting the three-wire weather-pack connector and inserting three short jumper leads to temporarily reconnect the circuit. Performing a minimum idle speed adjustment will probably cause the TPS to need adjustment as well.

Injector O-Rings

The O-ring that seals between the bottom of the injector and the manifold is a potential source of vacuum leaks. Carefully examine the O-rings and/or replace them when the injectors are serviced.

3.8-L Turbo (SFI) Injector Leads

Because the injectors are pulsed individually and in firing order on the 3.8-L turbocharged engine, the wires that power the injectors must be attached in the firing order. These wires are color-coded.

Fuel Line O-Rings

Threaded line connections between the fuel pump and the fuel rail may use O-rings to reduce the potential for leaks. They should only be replaced with O-rings designed to tolerate exposure to gasoline.

Fuel Flex Hose

The fuel flex hose used on PFI is internally reinforced with steel mesh. No attempt should be made to repair it. It should be replaced if it becomes unusable or questionable.

WARNING: For personal safety, the factory-recommended procedures should be carefully adhered to when servicing fuel lines or fuel line connections. The fuel is under high pressure, and failure to comply with factory-recommended procedures can result in a fuel leak and fire.

SUMMARY

This chapter has focused on port fuel injection systems that use one injector per cylinder and are triggered by the computer, either in the firing order of the engine or simultaneously. We have seen the advantages port injection provides: a more accurately metered fuel delivery and the elimination of problems associated with distribution of an air/fuel mixture through the intake manifold. We have seen the method General Motors uses employing a cold-start injector to provide an initially richer mixture to aid in starting under low temperature conditions.

In this chapter, we considered the turbocharger boost controls for vehicles equipped with this accessory. These controls include a mechanism to modify boost using the wastegate, as well as a more sensitive spark advance system with a knock sensor.

We have seen the introduction of a stepper motor–controlled engine idle speed, using an air bypass to meter the amount of intake air around the closed throttle. We have also covered the EGR and AIR systems and how the computer monitors and controls them.

▲ DIAGNOSTIC EXERCISE

A sequential port fuel injected vehicle has been towed into the shop with a customer complaint of "Cranks but won't start." As the technician is verifying the symptom, he notices that he does hear the fuel pump operate for 2 seconds when he first turns on the ignition switch. In other tests, he finds that although power is supplied to the fuel injectors with the ignition turned on, there is no PCM pulse to any of the fuel injectors. At this point, what faults could be responsible for the no-start condition? What test(s) would you recommend be performed next to narrow the list of possible faults?

Review Questions

1. On PFI systems, only air is moving through the intake manifold when the engine is running, thus eliminating the concern for condensation of fuel vapors in the manifold runners. As a result, what systems that were used with TBI applications are now eliminated?
   A. Heated intake air (Thermac) system
   B. Early fuel evaporation (EFE) system
   C. Canister purge system
   D. Both A and B
2. What do most PFI systems use to prevent throttle blade icing?
   A. Heated intake air (Thermac) system
   B. Early fuel evaporation (EFE) system
   C. Canister purge system
   D. Coolant passage in the throttle body
3. To properly control the air/fuel ratio during cranking mode, the PCM relies primarily on input information relating to throttle position and which of the following?
   A. Engine coolant temperature
   B. Intake air temperature
   C. Engine load
   D. Exhaust oxygen content
4. During cranking mode, input from the TPS is important to the PCM to determine which of the following?
   A. How much to advance the spark timing
   B. How far to open the EGR valve
   C. Whether to initiate clear flood mode
   D. Whether to energize the fuel pump relay
5. What controls the fuel pressure regulator, causing it to vary fuel pressure between idle and WOT?
   A. The PCM
   B. A venturi vacuum signal
   C. A ported vacuum signal
   D. A manifold vacuum signal
6. Why is the fuel pressure increased as the throttle moves from idle to WOT?
   A. To provide more fuel flow through the injectors any time they are open under heavy load conditions
   B. To keep the pressure differential across the injectors constant under all engine operating conditions
   C. To keep the flow rate through the injectors constant any time they are open
   D. Both B and C
7. When a PFI engine is shut down, fuel vapors from the intake ports condense and form fuel deposits on the throttle blades. This condition can create all *except* which of the following symptoms?
   A. Hard starting
   B. Engine overheating

C. Erratic idle
D. Hesitation and surging

8. What type of signal does an AC MAF sensor send to the PCM?
   A. An AC voltage that ranges from 30 to 150 V
   B. A DC voltage that ranges from 30 to 150 V
   C. A digital frequency that ranges from 30 to 150 Hz
   D. A DC voltage that ranges from 0.5 to 5.0 V
9. When diagnosing a "Cranks but won't start" symptom on a PFI engine, a technician finds that there is no injector pulse from the PCM. Which of the following problems could cause this?
   A. The IAT sensor circuit is open, resulting in a 5-V signal to the PCM.
   B. The REF signal from the distributor's pickup coil has been lost.
   C. The ECT sensor circuit is open, resulting in a 5-V signal to the PCM.
   D. The fuel pump relay is defective.
10. What types of sensors are used by a C3I system to produce the crank and cam signals?
   A. Permanent magnet
   B. Optical
   C. Hall effect
   D. Piezoresistive
11. During engine cranking, a Fast Start Type III C3I ignition system enables the PCM to identify which ignition coil to fire first within which of the following?
   A. 120 degrees of camshaft rotation
   B. 360 degrees of camshaft rotation
   C. 120 degrees of crankshaft rotation
   D. 360 degrees of crankshaft rotation
12. A cold-start injector is controlled by which of the following?
   A. The starter circuit
   B. A thermo-time switch
   C. The PCM
   D. Both A and B
13. Which of the following is the purpose of the ESC module?
   A. To advance spark timing according to engine load and RPM
   B. To retard spark timing according to input from a detonation sensor
   C. To control fuel injector pulse width according to engine load
   D. To control idle RPM
14. On a PFI system, when does the PCM reference the count of the IAC's pintle valve by momentarily moving the valve to the closed position?
   A. Each time the ignition is turned off
   B. Each time the engine is started
   C. When the PCM sees 30 MPH from the VSS
   D. When the PCM sees 600 RPM from the tach reference signal
15. On a system with a dual-bed, three-way catalytic converter, during closed-loop operation the AIR system should direct air flow to which of the following?
   A. Intake manifold
   B. Exhaust manifold
   C. Oxidizing bed of the catalytic converter
   D. Atmosphere
16. An EGR valve is designed to allow some exhaust gas into the intake manifold to reduce which of the following?
   A. HC emissions
   B. CO emissions
   C. CO_2 emissions
   D. NO_x emissions
17. Technician A says that turbochargers increase engine performance by increasing the engine's volumetric efficiency. Technician B says that a wastegate is used to limit a turbocharger's boost pressure to avoid pre-ignition and engine damage. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
18. The TCC is designed to do all *except* which of the following?
   A. Increase performance potential during WOT operation
   B. Increase fuel economy

C. Eliminate hydraulic slippage in the torque converter during cruise conditions
D. Eliminate heat production in the torque converter

19. What is indicated if long-term fuel trim (block learn) numbers are higher than normal?
    A. The PCM is operating in open loop most of the time.
    B. The PCM is operating at base timing most of the time.
    C. The PCM has learned to compensate for a lean tendency and is adding fuel to the base fuel calculation.
    D. The PCM has learned to compensate for a rich tendency and is subtracting fuel from the base fuel calculation.
20. Technician A says that when replacing a PROM or CALPAK chip in a PCM, you should be careful not to touch the pins in order to avoid damage from static electricity. Technician B says that when replacing a PCM with a removable PROM chip, you should check the service bulletins to be sure you have the latest PROM update. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician

Chapter 12

Advanced General Motors Engine Controls

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Understand the primary features of the Northstar engine.
- ☐ Define the inputs and outputs that are used with the Northstar engine.
- ☐ Describe the difference between the functions of a powertrain control module (PCM) and a vehicle control module (VCM).
- ☐ Explain how Central Multiport Fuel Injection (CMFI) or Central Sequential Fuel Injection (CSFI) is different from standard port fuel injection.
- ☐ Understand the primary features of the Generation III V8 engine.
- ☐ Understand the primary features of the Premium V6 engine.
- ☐ Explain how General Motors' Variable Valve Timing system functions.
- ☐ Describe some of the features of the Saturn 1.9-L engine application.

KEY TERMS

Active Fuel Management (AFM)
Background Noise
Belt Alternator Starter (BAS)
Close-Coupled Catalytic Converter
Displacement on Demand (DOD)
EEPROM
Electronic Throttle Control (ETC)
Engine Metal Overtemp Mode
Flywheel Alternator Starter (FAS)
Hot-Wire Air Flow Sensor
Misfire Detection
Primary Oxygen Sensors
Quad Drivers/Output Drivers
Secondary Oxygen Sensor
Torque Management
Variable Valve Timing (VVT)
Waste Spark

Like all manufacturers, General Motors (GM) continues to develop engines and computerized engine control systems that utilize more advanced levels of technology. In this chapter, we present some of the more recent GM computerized engine control systems. It is advantageous for the reader to be familiar with the information contained in the previous chapters.

Specifically, in this chapter we will take a look at the 90° V-engines that are produced by GM's *Premium Engine Group* and the features associated with them. Most of the Premium V-engines are V8s and are classified under the name "Northstar." However, a shortened version of this engine was also built as a V6 (known either as a Premium V6 engine or as the Short North engine). The V6 version has many features that are also used on the Northstar V8, so much of the following discussion of the Northstar applies to the V6 version as well. Also, during the discussion of the Northstar engine, we will look at some of the newer technologies that have been implemented on that engine, including **Variable Valve Timing (VVT),** which is the ability to change the timing of the camshaft relative to the crankshaft, and **Electronic Throttle Control (ETC),** which is the ability to electronically control throttle position without the use of a physical throttle cable.

We will also take a look at a Generation IV small-block V8 engine that was introduced on the 2005 Chevrolet C6 Corvette and some of the ways it differs from Chevrolet small-block V8s. We will also discuss GM's **Active Fuel Management (AFM)** technology, which is used to effectively change an engine's displacement. We will complete this chapter with a look at some of the features associated with GM's 42-V Chevrolet Silverado "hybrid" light truck, which was introduced in the 2004 model year.

NORTHSTAR ENGINE OVERVIEW

GM builds a large number of different engines of various sizes and configurations; in this section we will focus on the Northstar engine. This engine was introduced in the fall of 1992 on the 1993 Cadillac Allante and is still being used, with some available technological upgrades, on current-year models. Originally known as the *Cadillac* Northstar engine, it was initially used only on Cadillac vehicles but has since found its way (in various configurations) into other model lines. With a 4.6-L displacement, this 32-valve, all-aluminum (block and heads), 90-degree V8 engine has chain-driven dual overhead camshafts (DOHC).

The original Northstar, the "L37," was designed as a transverse V8 for front-wheel-drive vehicles. It was tuned for responsiveness and power and was used on the 1993 Allante and in following years on the DeVille Concours, Seville STS, and Eldorado ETC.

This was followed by the "LD8" Northstar engine, which was also designed as a transverse V8 for front-wheel-drive vehicles but is tuned for more sedate use, providing higher torque than the high-revving L37 it has replaced. It has been used on the DeVille, Eldorado, and Seville SLS. Currently, the LD8, a 275-horsepower (hp), 10:1 compression engine with 300 foot-pounds of torque, is standard in the Deville and Deville DHS. This version is also offered in the Pontiac Bonneville beginning in the 2004 model year. A 290-hp, 10:1 compression version with 285 foot-pounds of torque is standard in the DeVille DTS. GM also plans to offer this engine as an option in the new 2006 Buick Lucerne, with ETC added to it.

Another version of the Northstar was developed for Oldsmobile and was used in the Aurora. It was a specially designed 4.0-L V8, known as the "L47," that was based on the Northstar. The L47 produced 250 hp and 260 foot-pounds of torque. It was introduced in the fall of 1994 on the 1995 Oldsmobile Aurora and was used through the 2003 model year. In 2004 the Aurora was discontinued, and the L47 has not been used since.

Another engine based on the Northstar's design was a V6 known as the "LX5." This was a 3.5-L engine that was more directly based on the Oldsmobile Aurora L47. As a V6 produced by GM's Premium Engine Group, which also designed the Northstar, it was sometimes called the "Premium V6 (PV6)" engine, the "Short North," or the Shortstar. It was used only in the 1999 Oldsmobile Intrigue and in the 2001–2002 Oldsmobile Aurora as a base engine. It also has not been used since.

For the 2004 model year, the LD8 was modified substantially for longitudinal use so that it could be used in rear-wheel-drive vehicles. This version is known as the "LH2" Northstar engine and is sometimes referred to as a second-generation Northstar. The LH2 is a 320-hp, 10.5:1 compression engine with 310 or 315 foot-pounds of torque (depending on model); it became available in the 2004 STS, 2004 XLR, and 2004 SRX sport-utility vehicle. The 320-hp LH2 also has a VVT system that can be continuously varied on all four camshafts, discussed later in this chapter. And the LH2, when mounted in the 2004 XLR, became the first Northstar engine to get ETC, also known as "drive-by-wire," also discussed later in this chapter.

The Northstar motor has direct mount accessories (including the water-cooled generator) to reduce noise. The transmission features Performance Algorithm Shifting (PAS) that alters shift timing in response to lateral acceleration. PAS also causes the transmission to downshift into the proper gear (and holds it there) as the vehicle enters and executes a turn.

General System Features

Overview. The heart of this GM engine control computer system is the PCM (Figure 12–1). It is a much faster and more powerful computer than those used previously to monitor and control engines for emissions quality, driveability, and fuel economy. In addition, the PCM is responsible for all the diagnostic functions required for compliance with OBD II regulations.

One precaution worth remembering: With the considerably increased number of diagnostic trouble codes (DTCs) in the OBD II system, technicians are often startled to find a huge number of DTCs stored. Check to see what circuits are involved: Often all the codes recorded are for a single circuit or a set of closely related circuits.

Among the engine and vehicle functions the PCM controls are:

- fuel mixture control
- ignition control
- knock sensor (KS) system (detonation control)
- automatic transaxle shift functions
- enabling the cruise control
- regulating the output of the generator (alternator)
- evaporative emission (EVAP) purge (canister purge)
- exhaust gas recirculation (EGR)
- air injection reaction (AIR)
- A/C clutch engagement control
- radiator cooling fan control
- traction control

PCM Learning. The PCM has a much more advanced learning capability than previous engine control computers, but resetting the system is relatively similar. But if erroneous data has somehow become recorded in memory, the technician can no longer merely disconnect the battery for a few minutes while the computer's volatile memory (keep-alive memory) deletes. Changes to the memory data may require the use of a dedicated scan tool to make the deletions. Finer discrimination learning comes as the system performs various tests and experiments, while the vehicle is driven at part throttle, with moderate acceleration. Some vehicle systems

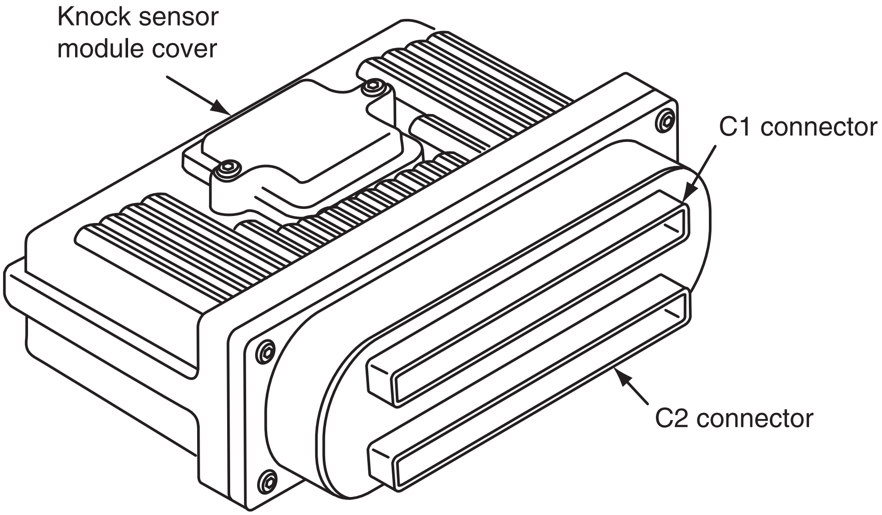


Figure 12–1 PCM.

also allow reprogramming of the control module with or without removal from the vehicle, a process called *flashing.*

Vehicle Identification IC Chips. Vehicle identification (VID) integrated circuit chips were introduced on GM vehicles in the late 1990s and are now commonly found in most major computers on a GM vehicle. In the same manner that body panels such as fenders and hoods have had VIN labeling for some years now that signify the vehicle they were originally manufactured as part of, major computers on the vehicle are now labeled electronically as to the VIN number of the vehicle they belong to. This is designed to reduce the potential for "chop shops" to successfully sell or use the major computers from a stolen vehicle.

The VID chip is a "one time write" IC chip; once the vehicle's VIN information has been programmed into the chip, it cannot be erased or overwritten with new VIN information. When a module with a VID chip is "remanufactured," the original VID chip must be replaced with an electronically blank chip in order to allow the module to be used again.

If a module with incorrect VIN information is installed in a vehicle, the instrument panel may falsely illuminate most or all of the warning lamps or, at the very least, a DTC for an incorrect module will be set. Unfortunately, this also means that replacement modules from junkyard vehicles are not recommended.

Sensor Reference Voltage. The PCM also provides a reference voltage to the various sensors and switches it uses to collect information on how the engine is running. To protect both the PCM and the sensor, this voltage is "buffered" in the PCM before it is sent to the switches and sensors. Many voltmeters, particularly analog voltmeters, may not give an accurate reading of this reference voltage because their impedance is too low. In order to be sure of making accurate measurements of reference voltage (and for that matter, of voltage throughout this system), use only digital voltmeters with a minimum of 10 MΩ input impedance—specification J 39200.

CAUTION: To continue a precaution that you should already be familiar with, when you work on these vehicles, you must be very careful to prevent damage to components by static electricity through the fingers. While it takes about 4000 V of static discharge for a person to feel even a slight zap, less than 100 V static discharge—1/40th of what can be felt—can be enough to damage a computer chip or memory unit.

Quad Drivers/Output Drivers. Internally, the PCM has many devices, including analog-to-digital converters, signal buffers, counters, timers, and special drivers. It controls most components, as car computers have for many years, by completing the circuit to ground (the components' power source usually comes from the ignition switch or some other source). These power transistors are solid-state on/off switches, often called **quad drivers/output drivers.** If the switches are surface-mounted in a group of four, they are quad driver modules; if the switches are surface-mounted in a group of up to seven, they are output driver modules. Certain switches may go unused on a particular vehicle, depending on its model year, accessory list, and so on.

Torque Management. Besides the functions normally provided by an engine control computer, this PCM also works to control—that is, to reduce—engine torque under certain circumstances. Torque reduction is performed for three reasons:

1. To prevent overstress of powertrain components.
2. To limit engine power when the brakes are applied.
3. To prevent damage to the vehicle or powertrain from certain abusive driving maneuvers.

To calculate whether to employ its torque-limiting functions, the PCM analyzes manifold pressure, intake air temperature (IAT), spark advance, engine speed, engine coolant temperature (ECT), the engagement or disengagement

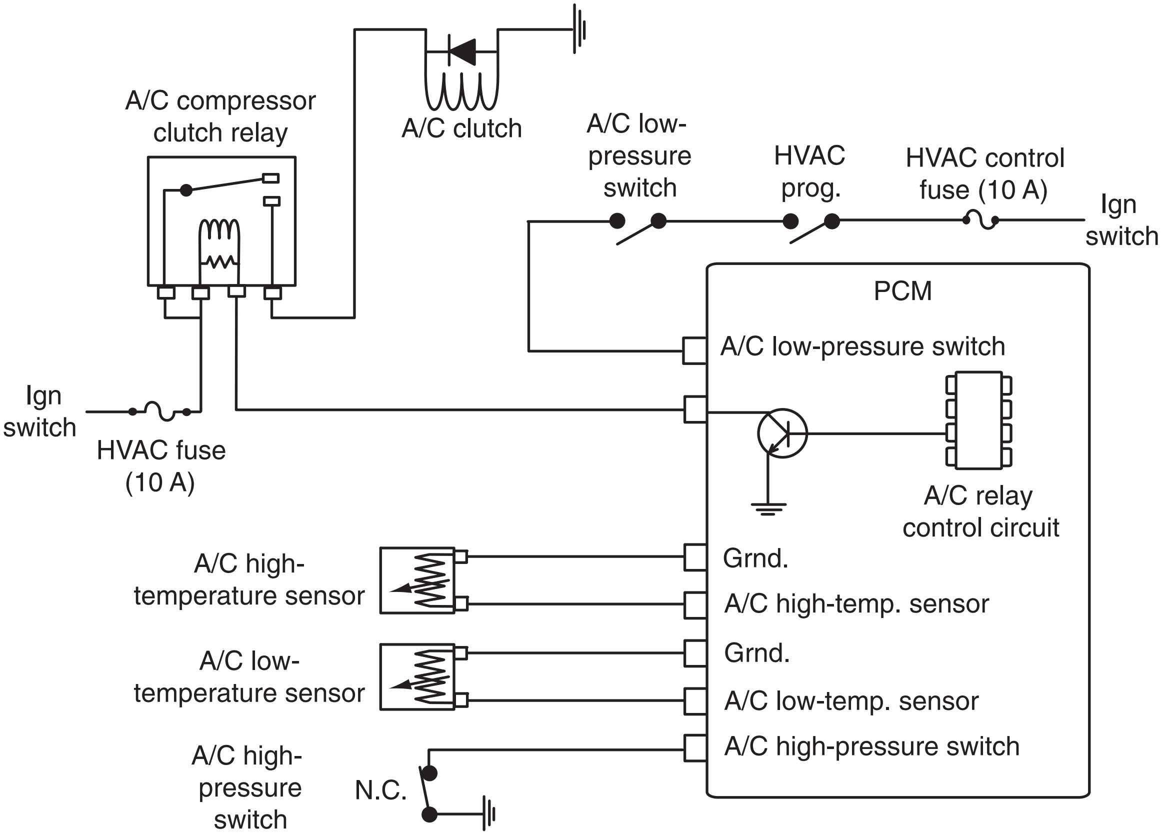


Figure 12–2 A/C compressor clutch control circuit.

of the A/C clutch through its control circuit (Figure 12–2), and the EGR status. It also considers whether the torque converter is locked up, what gear the transmission is in, and whether the brakes are applied. When the numbers add up to torque reduction, the PCM's first strategy is to reduce spark advance to lower engine torque output. In some more extreme cases, the PCM can also shut off fuel to one or more cylinders to further reduce engine power.

There are several occasions when **torque management** is likely to come into play:

- during transaxle upshifts and downshifts
- when there is hard acceleration from a standstill (traction control)
- if the brakes are applied simultaneously with moderate to heavy throttle
- if the driver initiates abusive or stress-inducing actions, such as shifting gears at high open throttle angles

In the first two cases, the operation of the torque management will probably not be noticeable.

Traction Control. The PCM is also responsible for the vehicle's traction control system. If the computer learns from the wheel speed sensors that the drive wheels are slipping during acceleration, it can individually apply the respective brake to prevent spin. In extreme cases, the torque management system can reduce engine torque as well, disabling as many as seven of the fuel injectors to do so. This strategy will not be adopted, however, if any of the following conditions occur:

- ECT is below 40°F.
- Engine coolant level is low (there is a sensor for this purpose).
- The engine is at a speed below 600 RPM.

If the traction control system is disabled for any of the above reasons or a system failure, the TRACTION OFF light will come on in the driver's information panel.

The torque management system can sometimes have surprising consequences. If a car is running under cruise control and encounters slippery pavement—perhaps slick ice—the wheel speed sensors will report extremely rapid acceleration. The traction control, among its other measures, will shut off the cruise control. Not only will it shut off the cruise control, but it will also disable it, set a code, and leave the subsystem disabled until the code is deleted by a technician. Various other problems, such as a slipping transaxle, can have the same effect.

Information Functions. The PCM also works with the BCM as well as other control modules to provide the driver with a variety of informational messages. These messages have to do with everything from engine and transmission oil life to remaining coolant level or windshield washer fluid level.

Ignition and Fuel Start-Up. The engine uses a four-coil **waste spark** ignition system, as described in Chapter 11. When the engine is cranked, the ignition control module (ICM) monitors crankshaft position sensor signals to determine which coil to fire first. Once the module determines the coil timing, it sends a fuel reference signal to the PCM. Upon reception of that pulse, the PCM pulses all eight injectors once simultaneously. It then leaves all the injectors off for two full engine crankshaft revolutions. This provides each cylinder with enough fuel for one power stroke. During those two revolutions, a camshaft position (CMP) signal should reach the PCM, and it can begin to trigger the injectors in the proper sequence. Should there be no CMP signal, the PCM will choose to begin sequential fuel injection with a random cylinder, although the chances are eight-to-one against its being correct. If the PCM chooses to begin sequential injection with an incorrect cylinder, the engine will still run, but the performance level will be somewhat reduced.

NORTHSTAR INPUTS/OUTPUTS

While modern vehicles of most makes (other than GM) use either a strict manifold absolute pressure (MAP)/speed density calculation or a strict mass air flow (MAF) measurement with regard to engine load, GM vehicles are unique in this area. The Northstar 4.6-L engine, like many newer GM engines, does not use a strict MAF sensor strategy but, rather, uses a combination MAF/MAP strategy to monitor engine load. The MAF sensor serves as the primary engine load sensor, but at times the PCM uses MAP sensor values to back up engine load calculations. The MAP sensor is also used by the PCM to help it test EGR flow rate and leakage as specified by OBD II standards. Also, an IAT sensor is present to help the PCM calculate engine load from MAP sensor values. The IAT sensor is not necessary when using the MAF sensor to measure engine load for fuel control purposes, but it is still used by the PCM for other reasons.

Mass Air Flow Sensor

The MAF sensor uses a **hot-wire air flow sensor** device to measure the air flow rate (Figure 12–3). It works by maintaining the hot wire at a specified temperature above ambient temperature. A second wire senses the ambient temperature. The hot wire is placed in the air stream and cooled by the intake air. The current required to keep the wire at the specified temperature corresponds closely to the amount of air entering the

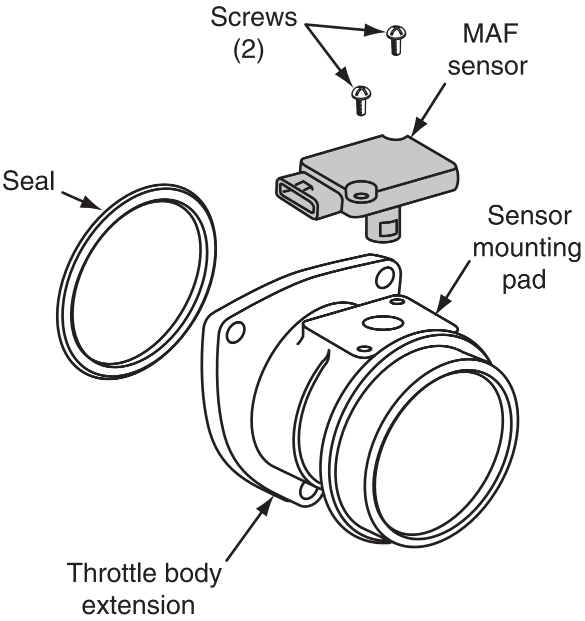


Figure 12–3 MAF sensor.

intake manifold by mass. Internal circuits in the MAF sensor convert the current required to keep the hot wire at the specified temperature into a frequency signal sent to the PCM. This air flow information is used in the calculation of fuel injector pulse width.

Manifold Absolute Pressure Sensor

The PCM gets engine load and barometric pressure information from the MAP sensor (Figure 12–4 shows the type commonly used). It receives a 5-V reference signal from the PCM, reduces it in accordance with the sensed pressure, and returns the reduced voltage as an indication of manifold pressure. The MAP voltage signal is an analog voltage that is reduced with reduced manifold pressure (high vacuum) and is increased with a rise in manifold pressure (loss of vacuum). The PCM compares the MAP signal against the throttle position sensor (TPS) signal, looking for discrepancies between them that would indicate one or the other is faulty. It

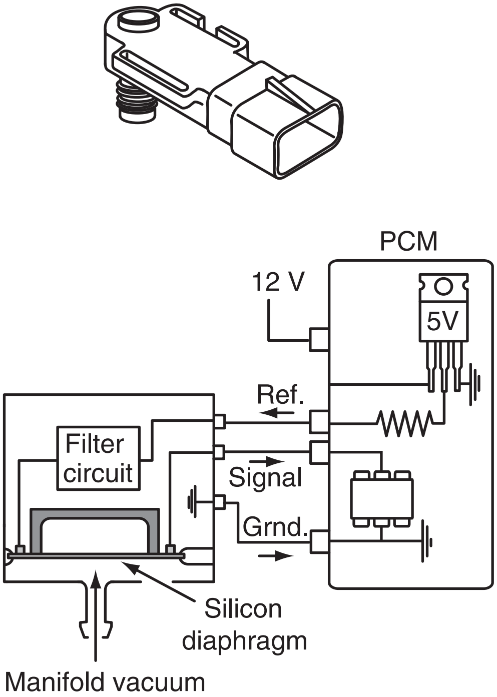


Figure 12–4 MAP sensor.

will notice if throttle position changes as little as 3.2 degrees in 0.5 second. If the MAP sensor's signal does not indicate a change of at least 4 kilopascals (about 0.6 PSI) during the same period, the PCM will set a trouble code for the MAP sensor.

The computer uses MAP sensor information to calculate spark advance and fuel mixture (including acceleration enrichment) and sometimes to determine whether to employ torque limitation measures. The fuel mixture is also affected by the pressure differential across fuel injectors, held steady by the fuel pressure regulator (Figure 12–5).

Temperature Sensors

Intake Air Temperature Sensor. The IAT sensor is a thermistor, a variable resistor that varies its resistance depending on its temperature. Receiving a 5-V signal from the PCM, it reduces

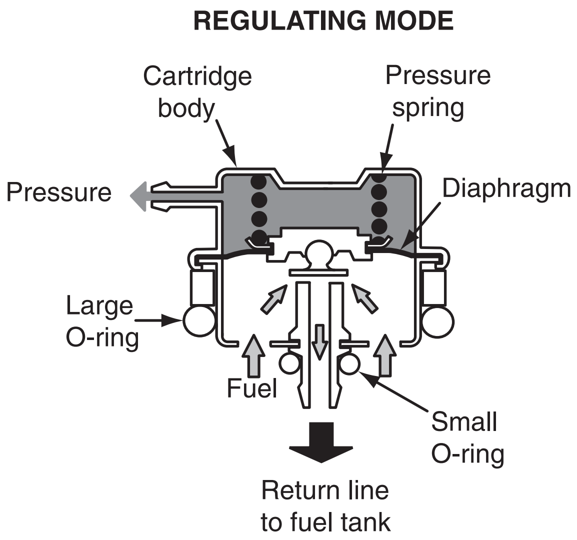


Figure 12–5 Fuel pressure regulator.

that depending on its temperature, modifying the signal corresponding to the IAT. As sensor temperature goes up, resistance goes down, so when the temperature is high, the signal will go to a low voltage.

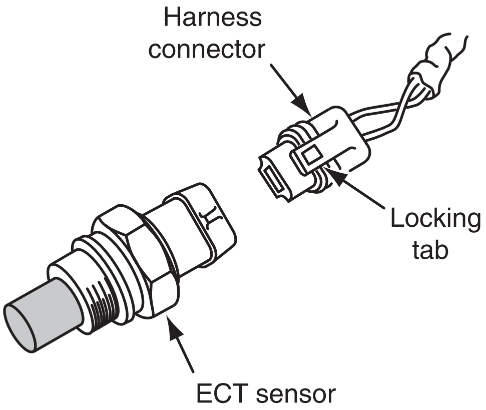


Figure 12–6 ECT sensor.

Engine Coolant Temperature Sensor. Because this engine has the ability to disable cylinders in the event of a total loss of coolant in order to protect the engine from high temperature (covered later in this chapter), the system uses a dual-range coolant temperature sensor (Figure 12–6). The PCM has within it a 3.65-KΩ resistor and a 348-Ω resistor in a series circuit (Figure 12–7). On a cold engine, 5 V (reference voltage) are passed through both

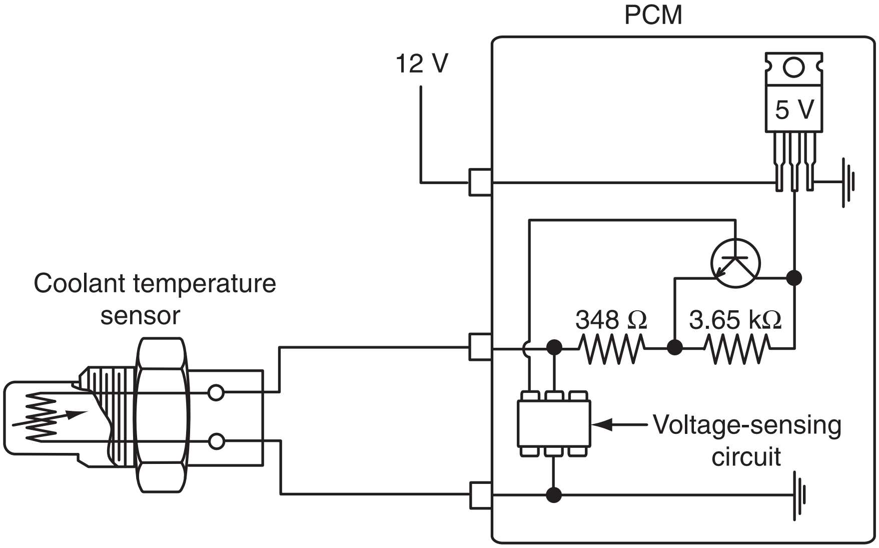


Figure 12–7 General Motors' dual-range temperature sensor circuit.

of these resistors before being passed out to and through the ECT sensor itself. The circuit is then connected to ground through the PCM. As with a standard ECT circuit, the PCM's voltage-sensing circuit monitors the voltage drop across the ECT sensor. As the engine coolant warms, the resistance of the ECT sensor's thermistor decreases, thereby also decreasing the voltage drop across the ECT sensor as measured by the PCM. However, this also means that the voltage drop across the two resistors in series within the PCM is increasing. That is, because all of the applied reference voltage will be used up by all of the resistance in the circuit (if the circuit is complete), as the voltage drop across the ECT sensor decreases, it is shifted to being dropped across the two resistors in series within the PCM. At about 122°F (50°C), when the voltage drop across the ECT sensor has been reduced to about 0.97 V (and the voltage drop across the two resistors in series is therefore about 4.03 V), the PCM suddenly completes a circuit that bypasses the 3.65-KΩ resistor. This causes the reference voltage to be applied through only the remaining 348-Ω resistor on the way to the ECT sensor. This has the effect of suddenly shifting much of the voltage drop to across the ECT sensor, thereby suddenly increasing the PCM's measured voltage to a value closer to reference voltage (Figure 12–8).

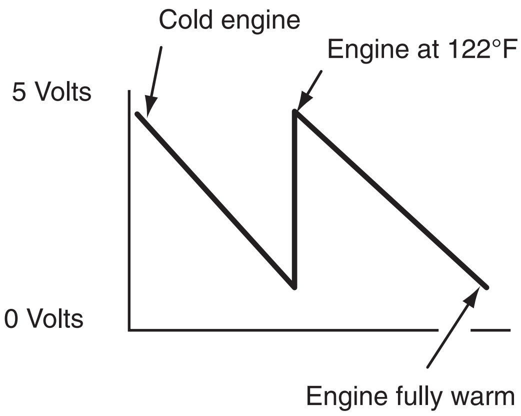


Figure 12–8 Dual-range ECT sensor waveform.

As the engine continues to warm, the PCM will see the voltage drop across the ECT sensor continue to decrease again.

Ultimately, this has the effect of extending the range of temperature that the PCM can measure into the *overtemp* range for the purpose of being able to control engine temperature in the event of a total loss of coolant. It also allows the PCM a more precise measurement of ECT throughout the entire temperature range because the voltage drop change across the ECT sensor as the engine warms exceeds the 5-V reference voltage applied to that circuit.

The information from this sensor, of course, also determines the operation of the radiator cooling fan.

One of the internal audit tests the computer automatically performs is to check to see whether the engine is warming quickly enough. After the engine has run 4.25 minutes, it checks to see that the coolant temperature is 41°F (5°C) or greater. If it is not, or if the coolant temperature falls below that temperature for more than 3 seconds, a code is set. The timer ratchets backward during torque management or traction control activity. Ordinarily, the only reason that an engine does not reach this temperature within the specified time is that a thermostat is blocked open. This assumes, of course, that the engine has been run under moderate load during the elapsed time. If someone merely started an engine at 40° below and let it idle for 4.25 minutes, it might not gain the 80 degrees, and a code would be set.

Throttle Position Sensor

The computer uses TPS information for calculating idle speed, fuel mixture, spark advance, deceleration enleanment, and acceleration or WOT enrichment. This sensor returns a proportionate signal: The lower the return voltage, the lower the throttle angle. The computer also compares (1) changes in throttle position with its internal clock to determine how quickly the throttle has been changed and (2) TPS with MAP information:

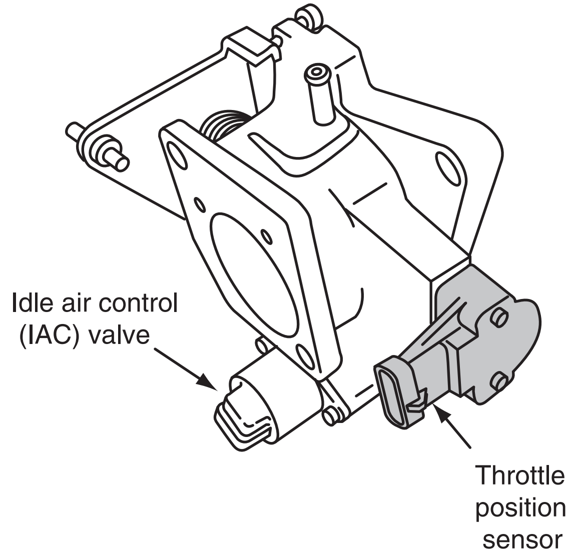


Figure 12–9 Throttle position sensor.

Any significant discrepancy indicates one or both circuits are faulty.

The TPS on this system is said to be self-adjusting (Figure 12–9). What that actually means is that it is not adjustable, but the computer learns what to expect from it and adjusts its calculation tables accordingly. For the self-adjustment, the computer assumes that the throttle is closed when the key is turned off with the throttle position signal at the same value twice in succession.

Heated Oxygen Sensor

The heart of any closed-loop fuel metering system is the oxygen sensor; this system uses a special heated sensor to bring it up to operating temperature as quickly as possible (Figure 12–10). The computer sends the sensor a bias voltage of 0.45 V. As long as this is the return voltage, the PCM stays in open loop. Once the oxygen sensor gets warm enough that the voltage generated by the sensor exceeds the bias voltage, the PCM removes the bias voltage and begins controlling the air/fuel ratio in closed loop.

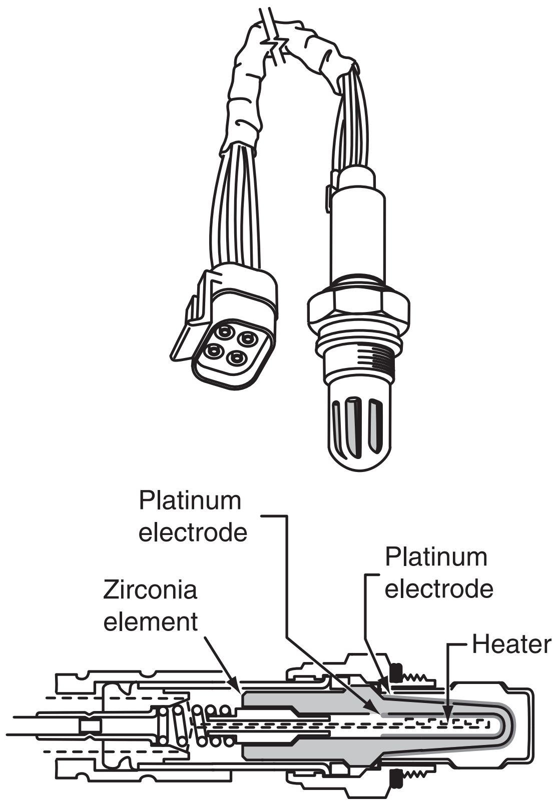


Figure 12–10 Heated oxygen sensor (HO_2S).

With OBD II comes a second oxygen sensor, functionally equivalent to the first but downstream of the catalytic converter. Its function is to check on the effectiveness of the converter. If all is well with the catalytic reduction and oxidation processes, things will be fairly uneventful at the **secondary oxygen sensor** (sometimes called the post-cat sensor). There should be little or no change of output voltage, since the converter will have used most of its oxygen to oxidize the carbon monoxide and hydrocarbons. When the post-cat oxygen sensor begins to mimic the signal of the pre-cat sensor, the catalytic converter is operating at a reduced efficiency; the computer, at a predetermined level of inefficiency, will set a fault code and illuminate the MIL.

On the Cadillac Northstar engine (and a number of other modern engines), there are two **primary oxygen sensors,** one on each cylinder bank. The individual oxygen sensors, obviously, report on the air/fuel mixture and combustion in the cylinders on their respective sides, but there is nothing in principle different from a single sensor system. Keep in mind, however, that the system uses *three* oxygen sensors including the post-cat oxygen sensor. The computer's trouble code recording capacity includes monitoring of each sensor and each sensor's heater circuit separately.

The PCM also has the ability to force the air/fuel ratio abnormally lean and rich in order to test both of the pre-cat sensors and the post-cat sensor for high voltage, low voltage, and response time in accordance with OBD II requirements. Likewise, the PCM tests the heater circuits for each of the oxygen sensors. Any failure will result in a specific DTC being set, initially as a pending DTC and then as a mature DTC.

Fuel Pump Feedback Circuit. The PCM gets a signal through the fuel pump relay confirming operation of the fuel pump. As on previous systems, the fuel pump is actuated for 2 seconds after the ignition key is turned on to prime the injectors for starting. After 2 seconds, the pump shuts off until there is a crankshaft (CKP) sensor signal. If the PCM detects a low voltage on the fuel pump circuit when the fuel pump relay is energized, it sets a DTC in memory.

Dual Spray Fuel Injectors

The Northstar engine, with four valves per cylinder, uses dual spray fuel injectorsthat spray fuel on the back side of each cylinder's two intake valves. For best performance, it is recommended that these injectors be properly aligned with the fuel rail according to the manufacturer's specifications.

Engine Coolant Temp Fuel Disable

Advertised by GM as an "extended distance" feature (called **engine metal overtemp mode**), this fuel disable feature allows the driver to "drive 50 additional miles after the engine has run out of coolant" to get the vehicle to a repair facility. This feature was first designed into the PCM's program on Northstar applications. Later, it also became a feature available on the Premium V6 and is now also available on other GM engines. If the PCM detects an ECT sensor value of 270°F, it disables the fuel injectors on every other cylinder in the engine's firing order, alternating with cylinders that are still contributing to engine performance. This allows the disabled cylinders to act as a heat transfer pump. The PCM then empowers the disabled cylinders and disables the empowered cylinders after a preprogrammed number of engine cycles, alternating them to control engine temperature until the driver is able to get the vehicle to a repair facility.

Misfire Detection

Among the most important capabilities mandated by OBD II are **misfire detection** and correction of misfire. A misfire means a lack of combustion in at least one cylinder for at least one "combustion event." A misfire pumps unburned fuel through the exhaust system, and while the catalytic converter can deal with an occasional puff of fuel vapor, a steady stream of it from a dead cylinder would soon overheat the converter and spill into the atmosphere. The PCM detects misfire by very closely monitoring minute changes in crankshaft speed. At higher speeds, these changes are measured and compared over two engine revolutions. If the system detects a dead cylinder, it will shut off the fuel injector to that cylinder, preventing the catalytic converter from overheating. Also, on some applications the PCM receives input from the antilock brake system's wheel speed sensors to determine when perceived cylinder misfire is simply the result of drive train influences due to a rough road surface.

Keep in mind that shutting off an injector does have an effect on closed-loop feedback systems. The camshaft and valves still work to move air from the intake manifold to the exhaust manifold.

The air pumped through the disabled cylinder contains a higher percentage of oxygen than the exhaust of the air/fuel mixture burned in the other cylinders. Since the oxygen sensor does not know where oxygen is coming from, it will report an over-lean condition to the computer, which will try to richen the mixture. On most engines, that much enrichment is beyond the capacity of the system because no amount of fuel added will burn the oxygen passing through the dead cylinder. The computer will set a trouble code and turn on the malfunction indicator light. If the misfire is steady, the computer will consider that an event with a high probability of damaging the catalytic converter. It will flash the Service Engine Soon light until the condition is no longer present or the engine is shut off. Such serious events are stored in the freeze frame and failure records for later retrieval and diagnosis.

When cylinder misfire is present, you should check to see whether two cylinders are involved. If there are, look for something shared by both cylinders, such as the common coil or exposure to the same vacuum leak.

Knock Sensor Circuit

An engine can withstand a small amount of spark knock for a short time, and this computer factors that into its spark advance calculations. The knock sensor (KS) must report a detonation event lasting longer than 99.99 ms for three continuous cycles. The response then is to retard spark until the knock disappears. The basic ignition (spark advance) map for the engine assumes a fuel with an octane equivalence of 87, but the system can manipulate spark (more or less advanced) to accommodate a higher or lower detonation resistance with different fuels. In general, the system will drive the spark advance right to the edge of knock to maximize fuel economy and reduce emissions problems.

The computer's KS is also used to detect KS *circuit* faults. Because the sensor is fundamentally a kind of microphone, and the computer sorts out what kind of noise is detonation and what is just ordinary engine noise, the **background noise** can be used to detect some circuit faults. If the background noise does not rise in an expected way with engine speed and load (as reflected by TPS and RPM through crank and cam sensors for a given period of time), it will record a KS fault, even if there is no knock.

Crankshaft Position Sensors

The system uses two crankshaft sensors (Figure 12–11) on the front of the engine block between cylinders 4 and 6. Crankshaft position sensor A is in the upper crankcase, and crankshaft position sensor B is in the lower crankcase. Both sensors extend into the block and are sealed with O-rings. There are no adjustments that can be made.

The pickups work like distributor pickups. As the reluctor on the crankshaft moves over the sensor, the coil generates an alternating, polarity-reversing signal that appears (after it goes through the buffer circuit) to the computer as an on/off/on/off signal. The reluctor ring under the sensors has 24 evenly spaced notches and an additional 8 unevenly spaced notches for a total of 32 (Figure 12–12). As the crankshaft rotates

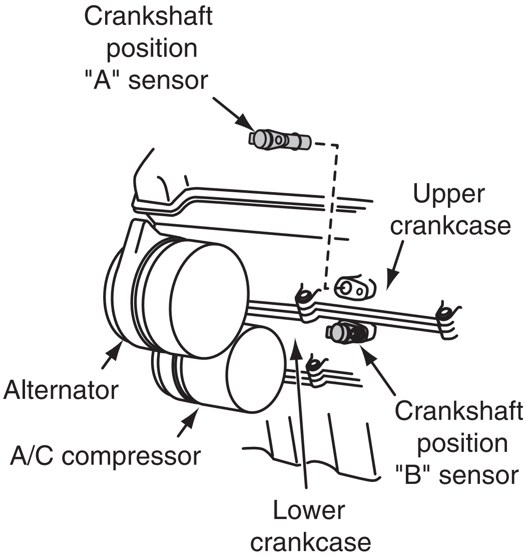

Crankshaft position "A" sensor
Upper crankcase
Alternator
A/C compressor
Crankshaft position "B" sensor
Lower crankcase

Figure 12–11 Crankshaft position sensors A and B.

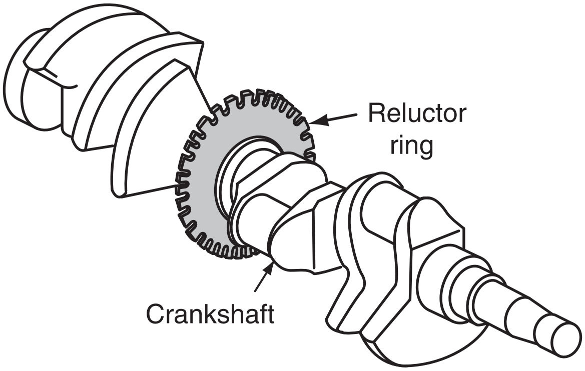


Figure 12–12 Crankshaft reluctor ring.

once, each sensor reports 32 on/off signals. Since the sensors are positioned 27 degrees of crankshaft rotation apart, this creates a pattern of on/off signals that enables the ignition control module (ICM) to identify the crankshaft position.

Camshaft Position Sensor Signal

The camshaft position (CMP) sensor is on the rear cylinder bank at the front of the exhaust camshaft (Figure 12–13). It extends into the cylinder head and is sealed with an O-ring. There are no adjustments.

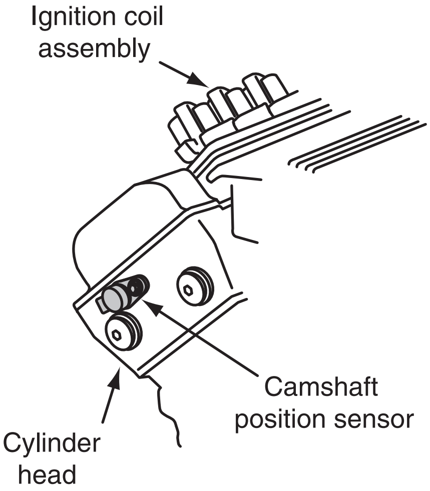


Figure 12–13 CMP sensor.

As the camshaft turns, a steel pin on its drive sprocket passes the magnetic pickup of the sensor (Figure 12–14). This generates an alternating, polarity-reversing signal similar to the crankshaft position sensor signal. This on/off signal, in time with the camshaft, occurs once every other crankshaft revolution.

Ignition Control Module

The ICM is on top of the rear camshaft cover (Figure 12–15). It performs these functions:

- monitoring the on/off pulses from the two crankshaft position sensors and the CMP sensor
- generating a 4X and 24X reference signal sent to the PCM for ignition control
- generating a camshaft reference signal sent to the PCM for fuel injection control
- providing an ignition ground reference for the PCM
- providing for the PCM's control of spark advance
- providing for "module mode," a limited means of controlling spark advance without PCM input—basically a limp-home running mode

The ignition module cannot be repaired; replacement is the only option if it develops a problem.

Ignition Coils

The 4.6-L Northstar was designed initially with a secondary ignition system of the waste spark variety, using four ignition coils to fire all eight cylinders. These coils were individually replaceable (Figure 12–15). In model-year 2000, the secondary ignition system was redesigned as a coil-on-plug (COP) design, using eight coils to fire the eight cylinders. Figure 12–16 shows a triple-coil cassette that was used on the V6 version of the Northstar, the 3.5-L LX5 engine described in the introduction. The three coils in this cassette were used to fire all three cylinders on one bank of this V6. The Northstar V8 uses a similar design.

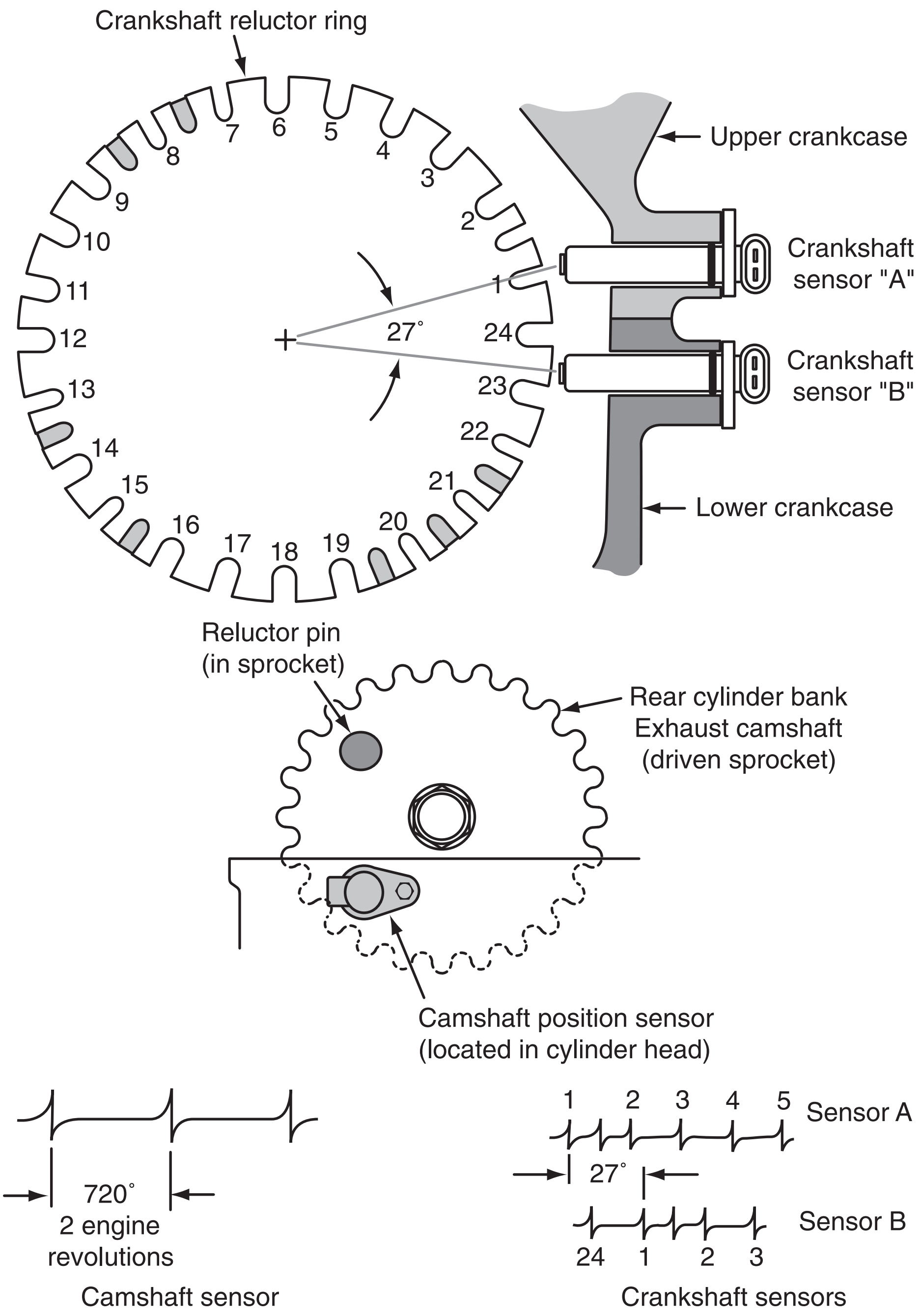


Figure 12–14 Crankshaft and camshaft position sensor configurations.

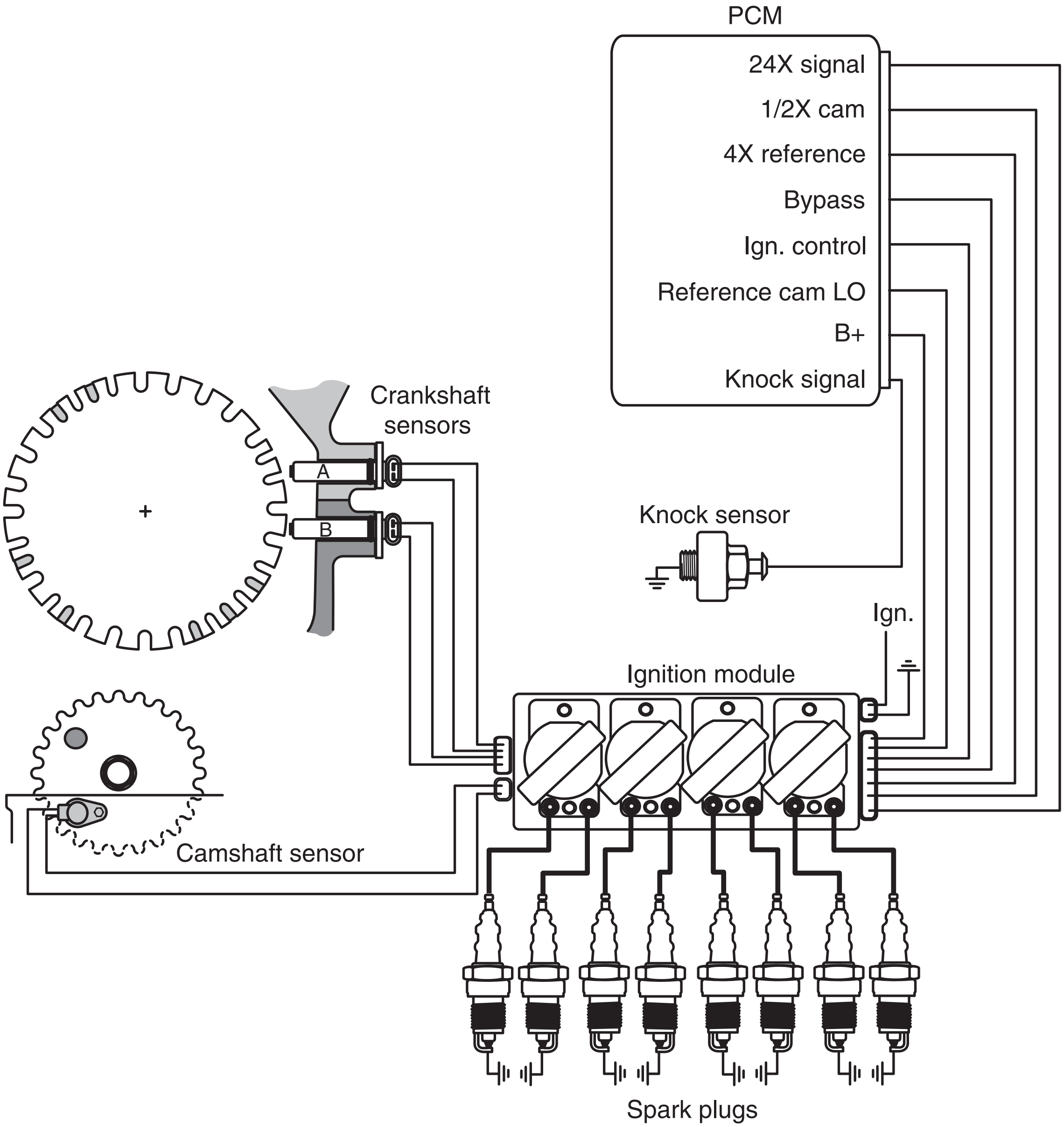


Figure 12–15 Ignition control system.

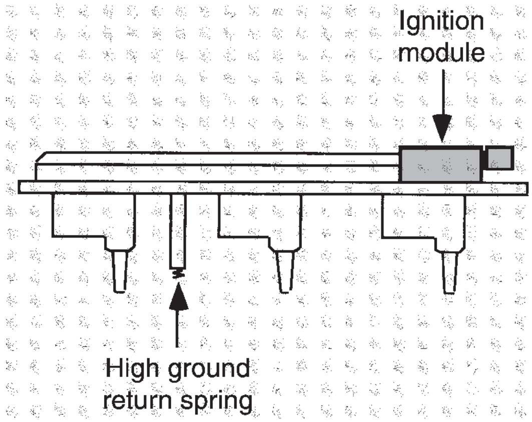


Figure 12–16 Ignition cassette.

Exhaust Gas Recirculation

The linear exhaust gas recirculation (EGR) valve used in this system can be tested by the PCM during specific driving operations. When the proper test conditions are met, the PCM cycles the EGR from off to on and back while monitoring the MAP signal. Obviously, opening another intake source should raise the intake manifold pressure (or decrease vacuum). (or similarly lower vacuum). The PCM repeats the test a number of times, comparing results to its program. If the results do not agree, it sets a DTC.

Catalytic Converter Efficiency Test

As explained in the section on oxygen sensors in this chapter, the PCM compares the signal from the two primary oxygen sensors with the single oxygen sensor downstream of the catalytic converter. If the converter is working properly, there should be very little variation in the signal produced by the secondary oxygen sensor. Should the secondary sensor produce a signal similar to those generated by the primary oxygen sensors, the PCM sets a code indicating a failed catalytic converter test.

Evaporative Emission Test

The PCM monitors the function of the evaporative emissions system by monitoring the vacuum switch in the line between the canister and the solenoid. The charcoal canister is virtually identical to those used in other vehicles for many years. When the solenoid is energized, allowing the engine to apply at least 12 inches of vacuum to purge the fuel vapors, the switch should open. The PCM monitors this by following the amount of time the vacuum switch is continuously open or closed during purging. When purging is supposed to occur, the PCM starts a timer. If the switch stays closed for at least 9 seconds, the test is failed; if the switch opens for at least 2 seconds continuously, the test is passed. This system has also been updated to allow the PCM to test the evaporative system and fuel tank for any leak larger than 0.020 inch, as specified by the OBD II enhanced requirements.

Idle Air Control System

The idle air control (IAC) system uses a stepper motor that works the same as those on earlier systems (Figure 12–17). In this system, the PCM matches the position it sets the IAC motor to with the achieved idle speed. If the idle speed

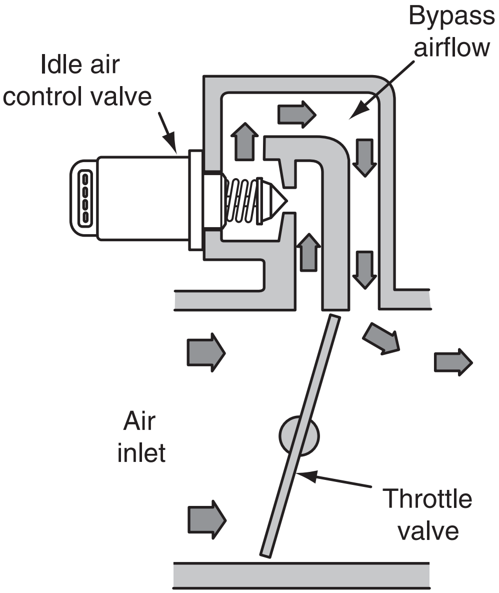


Figure 12–17 IAC valve.

is higher or lower than the desired speed by 80 RPM, the test is failed and a code is set.

Power Steering Pressure Switch

Normally the power steering (P/S) switch is closed, but when hydraulic boost pressure in the P/S system rises from 450 to 600 psi, it opens. The purpose of the switch is to inform the PCM when to increase idle speed slightly to compensate for the additional load during, for example, parking maneuvers. The PCM monitors the switch information against its other inputs and sets a DTC if the switch is ever open at a vehicle speed above 45 MPH as sensed by the vehicle speed sensor (Figure 12–18). This is a speed at which little or no P/S boost should be required.

PCM Self-Test and Memory Test

Like computers in earlier vehicles, this computer checks its internal circuits continuously for integrity. Likewise, it checks its non-removable electrically erasable programmable read-only memory **(EEPROM)** for the accuracy of its data. In computer terms, it tests the *checksum* of its files against what they are supposed to be and sets a DTC if they are different. Besides the hardwired memory, the PCM also monitors its volatile keep-alive memory. If that has been improperly changed or deleted, the PCM sets a DTC. *Note:* Such a code will be set when the battery is disconnected for more than a brief instant.

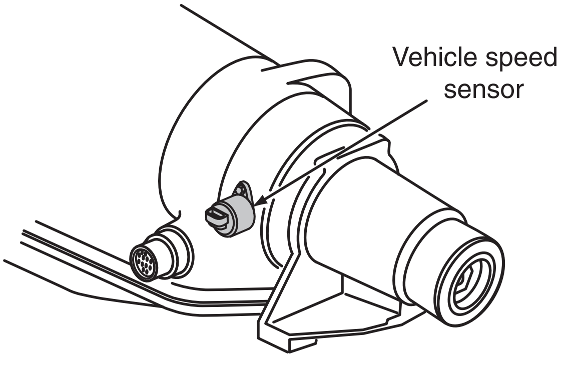


Figure 12–18 Vehicle speed sensor.

PCM Memory and the EEPROM

Instead of the fixed, unalterable PROM of previous years, the PCM has an EEPROM it uses to store a large body of information. While the EEPROM is soldered into the PCM and is not service-removable, it can store data, like the PROM, without a continuing source of electrical power. The PCM uses it as a storage bank for its throttle position/learned idle control tables, its transaxle adapt values, its transmission oil life information, its cruise control learning, and more. The EEPROM includes several areas available to store this data, and the PCM moves the data to a good location if there is damage to an earlier place. It will store a code if internal damage prevents the EEPROM from storing the information. The same data is stored in the keep-alive memory, so even if there is an EEPROM failure, the driver will probably not notice any difference. If the EEPROM defect code is set, the PCM must be replaced since the EEPROM is not removable.

Pass-Key Decoder Module

As part of an antitheft system, the PCM gets information from the pass key decoder module to identify the key used for the ignition switch and steering lock. If the wrong key is used or if the system fails, the PCM disables the fuel injection system to prevent theft of the vehicle.

CADILLAC LH2 NORTHSTAR UPGRADES

Billed as the second-generation Northstar, the LH2 4.6-L incorporated several modifications for longitudinal use, including relocation of the water pump to the front of the engine. This allows it to be used in both rear-wheel-drive and all-wheel-drive applications. In the 2004 model year, Cadillac began offering the LH2 version of the Northstar in the STS, XLR, and SRX sport-utility vehicle. (The XLR is the Cadillac model with the automatic retractable hardtop.) The LH2 introduces a number of firsts for the Northstar engine.

The compression ratio was increased from 10:1 to 10.5:1, and the intake and exhaust manifolds, along with the cylinder head ports, were designed to be less restrictive. A new air induction system was used, designed to enhance the engine's volumetric efficiency, as well as to improve the manifold's noise attenuation. **Close-coupled catalytic converters** are used, mounted directly adjacent to the exhaust manifolds, thereby allowing them to reach operating temperature more quickly following a cold start. Variable valve timing (VVT) was added and the EGR system, along with the associated emissions hardware, was eliminated. Also, electronic throttle control (ETC) was added to eliminate the traditional throttle cable.

Variable Valve Timing

The VVT system on the Northstar LH2 engine uses a mechanism called a "cam phaser" on the front end of each camshaft. The camshafts are designed with a helical spline that allows them to change their position in relation to the camshaft drive sprocket (Figure 12–19). This, in turn, changes the camshaft's relationship to the crankshaft, thus effectively changing cam timing. The PCM controls a hydraulic solenoid, which can apply oil pressure to either side of the cam phaser piston, thus moving it in either direction. In one direction, cam phaser piston movement advances valve timing. In the other direction, cam phaser piston movement retards valve timing. The PCM, using the CMP and CKP sensors (Figure 12–20), is able to calculate the relationship of the camshaft to the crankshaft and, therefore, is able to determine the amount of advance or retard.

On the LH2 Northstar engine, 4-cam continuous VVT is used. This means that on this application the PCM can control cam timing for both of the intake cams and both of the exhaust cams

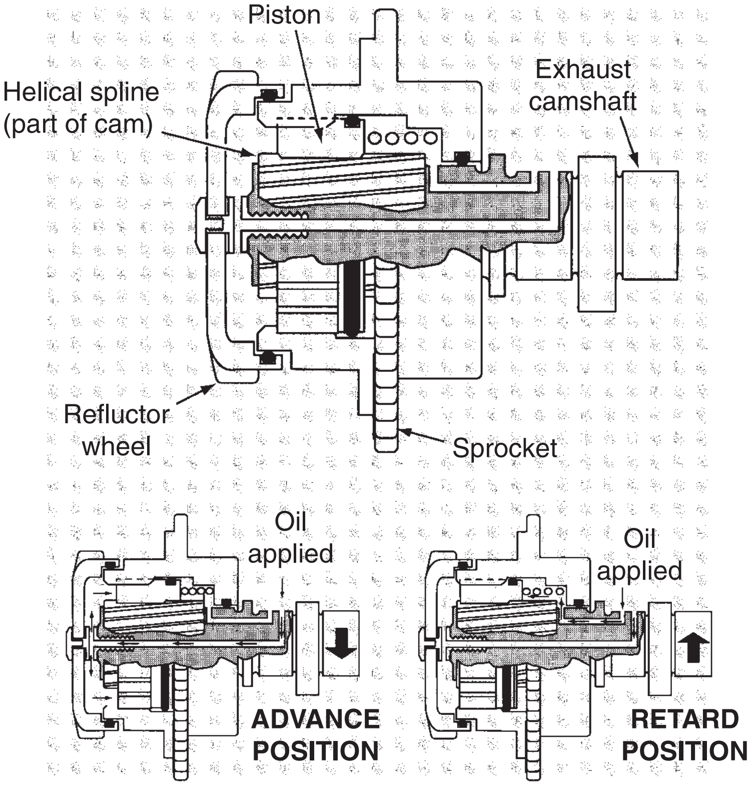


Figure 12–19 General Motors' VVT system.

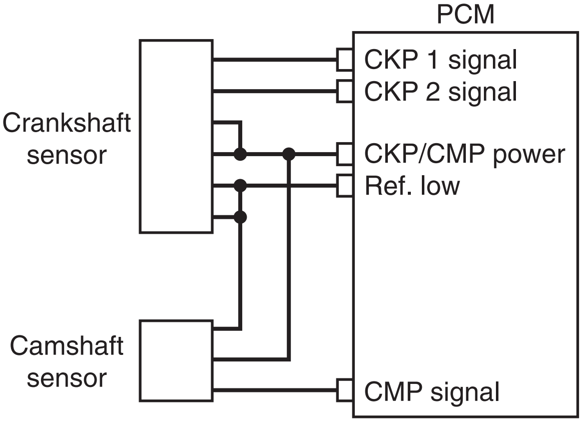


Figure 12–20 Crankshaft/camshaft sensor circuit.

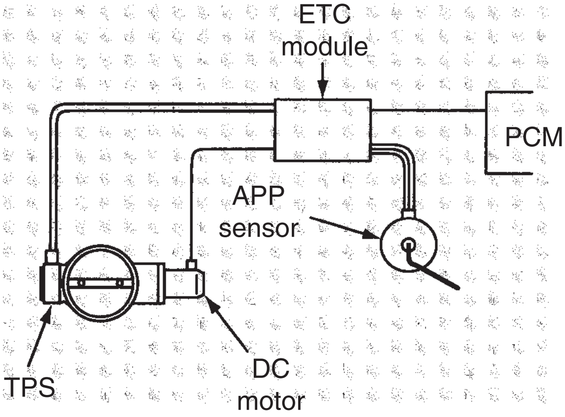


Figure 12–21 ETC components.

in a continuous fashion (unlike some engines in which only one of the camshafts, either the intake cam or the exhaust cam, can be varied in its timing). On the LH2, each of the two intake cams can be varied by as much as 40 degrees from one extreme to the other, and each of the two exhaust cams can be varied by as much as 50 degrees from one extreme to the other. The PCM is able to either retard or advance the selected cam within the total potential range of adjustment. The PCM positions the cams for smooth engine operation when at low RPM. Under high RPM and load, the PCM positions the cams for best performance while keeping NO_x emissions under regulated specifications.

Electronic Throttle Control

Originally known as a throttle actuator control (TAC) system, the ETC system, as it is now called, controls throttle plate movement electronically and eliminates the need for the traditional throttle cable. The ETC system is often referred to generically as a "drive-by-wire" system. The ETC system provides for several advantages, including lower emissions and quicker throttle response. This system was introduced on GM Generation III V8s in the 1999 model year and was added to the Cadillac Northstar LH2 in the 2004 model year.

The components of the LH2's ETC system include an ETC module (originally called a TAC module), a throttle position sensor (TPS) to monitor throttle plate position, a DC motor that serves as the actuator used to control throttle plate position, and an accelerator pedal position (APP) sensor. In basic computer theory concerning an engine with a cable-operated throttle plate, the TPS is said to give the PCM information concerning *driver demand.* In an ETC system, driver demand information now originates at the APP sensor (Figure 12–21).

The TPS is a two-channel potentiometer assembly, meaning that the TPS assembly contains two potentiometers and thus sends two signals to the ETC module. The APP sensor is a three-channel potentiometer assembly (Figure 12–22), meaning that the APP sensor assembly contains three potentiometers and sends three signals to the ETC module. In most applications, the potentiometers in the APP sensor operate electrically between different high and low values and/or in different directions. This allows the ETC module to more precisely interpret exact throttle position, as opposed to all potentiometers delivering exactly the same voltage values at a given throttle position. The APP sensor is located in a throttle pedal assembly that is spring-loaded to give the driver a realistic pedal feel.

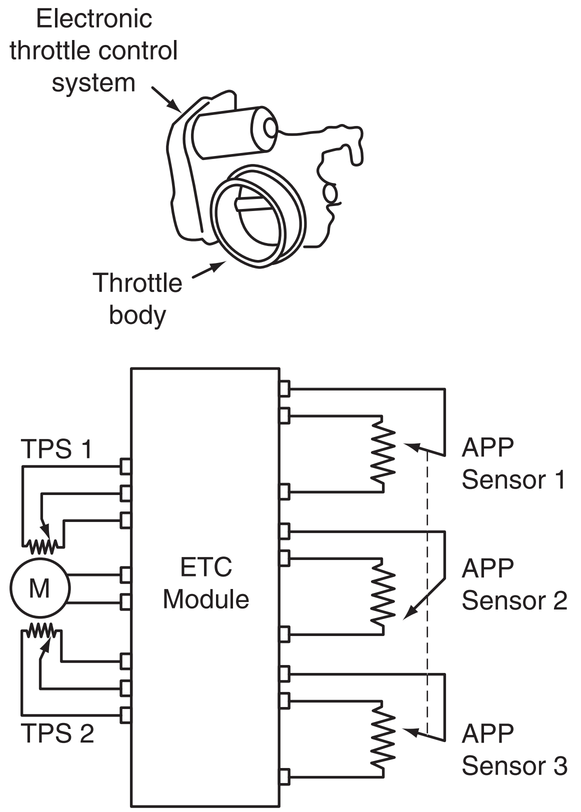


Figure 12–22 GM's ETC system, showing the TPS and APP circuits.

The ETC module commands the DC motor to open or close the throttle plate(s) using bidirectional pulse width modulated commands. That is, it can issue pulse width commands that instruct the motor to move the throttle plate(s) slowly or rapidly. And "bidirectional" simply refers to the fact that polarity applied to the motor can be reversed to move the throttle plate(s) in either direction (opening versus closing).

Compared to a cable-operated system, an ETC system provides quicker throttle response. To increase engine RPM and vehicle speed in a cable-operated system on a fuel-injected engine, both the amount of fuel and air entering the engine must be increased. The driver controls the volume of air allowed to enter the engine using the throttle cable, but the PCM controls the fuel. For the PCM to know to add additional fuel in a cable-operated system, the following must happen:

- The driver must move the throttle pedal.
- The throttle pedal must move the throttle cable.
- The throttle cable must rotate the throttle shaft, thus opening the throttle plate(s) to allow additional air to enter the intake manifold. Simultaneously, this action physically moves the TPS.
- The TPS must send the PCM a signal indicating that the throttle has opened the throttle plate(s).

In an ETC system, movement of the throttle pedal operates the APP sensor directly and immediately sends the signal to the ETC control module to increase engine speed. This signal is instantly relayed from the ETC module to the PCM using a high-speed serial data bus (using the CAN system discussed in Chapter 9). In an ETC system, the PCM controls both air and fuel, unlike the cable-operated system in which the driver controls the air and the PCM only controls the fuel.

Utilization of an ETC system also has some other benefits:

- The PCM can use the ETC system to control engine torque directly when the traction control feature mandates it.
- The dedicated cruise control (speed control) servo is eliminated and speed control becomes a simple function of the PCM, no longer requiring additional hardware to control throttle position.
- The IAC actuator is eliminated. The PCM can now control idle RPM directly without the use of additional dedicated hardware.

Cadillac XLR Keyless Access System

The Cadillac XLR uses a smart key system that utilizes antennas within each front door, the trunk, and the instrument panel. If the wireless key transmitter is within 1 meter of the lock cylinder on either front door or the deck lid, a touch pad allows the driver/passenger to open the door or deck lid without having to push any buttons on the transmitter or insert a key. Similarly, a smart ignition switch allows the driver to start the vehicle without having to insert the key in the ignition switch. With the vehicle in park and the brake pedal depressed, simply push the ignition button on the instrument panel. When the PCM recognizes that the keyless entry transmitter is inside the vehicle, it allows the XLR's Northstar engine to start. In practical use, the smart key system allows a driver to enter and drive away this vehicle with the key still in a pocket (or purse, sitting on the front seat).

CADILLAC HFV6

The GM Holden plant in Port Melbourne, Victoria, Australia, along with the GM engine plant in St. Catharines, Ontario, Canada, will share production responsibilities for producing a "High Feature V6" engine (HFV6, as it is called). Billed as a "Global V6," this engine is produced in four sizes: 2.8-L, 3.2-L, 3.6-L, and 3.8-L. These engines are provided to Holden, Cadillac, Buick, Chevrolet, Alfa Romeo, Saab, and other GM brands. It will also likely be provided to some non-GM brands in years to come. Cadillac is the first to get the HFV6 engines onto the U.S. market, a 3.6-L that was first offered in the 2004 Cadillac CTS. It also became available in the 2005 Cadillac STS. The Cadillac 3.6-L HFV6 produces 255 hp with 252 foot-pounds of torque. It is designed to accommodate both front-wheel-drive and rear-wheel-drive applications.

Like the Northstar LH2 engine, the HFV6 is an all-aluminum engine with chain-driven dual overhead camshafts (DOHC) and four valves per cylinder. All four camshafts use continuously VVT, also called *cam phasing,* with cam phasers on each of the four camshafts. Like the LH2, the HFV6 features ETC and a coil-on-plug (COP) ignition system. This engine also features pressure-actuated oil squirters that douse the bottom of the pistons and surrounding cylinder wall with engine oil to help cool the pistons.

The HFV6 not only produces a remarkable amount of power but also has an exceptionally wide power band, spanning a 3000 RPM range. Peak torque is reached at 3200 RPM, and peak horsepower is reached at 6200 RPM. Look for this engine on many more GM vehicles in the near future.

GM GENERATION III SMALL-BLOCK V8S

GM Small-Block V8 Overview

The GM Generation II small-block V8 was introduced as a 5.7-L engine on the Corvette in 1992. This engine was dubbed the "LT1" and had a rated 300 hp. The LT1 also became available in the mid-1990s as a 4.3-L V8, which was visually almost indistinguishable from the 5.7-L. The LT1 used either four-bolt mains (Corvette) or two-bolt mains. The LT1 was easily recognized by the optical distributor that was located on the front end of the camshaft, behind the water pump (described in Chapter 11).

In 1997, GM introduced the Generation III small-block V8, known as the "LS1," in the Corvette. Rated at 345 hp, this engine was equipped with six-bolt mains and is 53 pounds lighter than the LT1 it replaced. The Generation III V8 was produced in several different sizes, including 4.8-L, 5.3-L, 5.7-L, and 6.0-L. These engines also use a different firing order than the traditional GM V8. The new firing order is 1-8-7-2-6-5-4-3. Light trucks use a variation of the LS1 in the 4.8-L, 5.3-L, and 6.0-L sizes. The light truck variation of the LS1 is called a "Vortec V8."

In 2001, an LS6 version of the LS1 became available in the Corvette, with an increase in the rated horsepower to 385 hp.

Detonation Sensor

The GM Generation III V8s have a modified spark knock detection circuit in the PCM. Previously, a 5-V DC source was used to detect circuit integrity for shorts and grounds. Measured at the

PCM connector with a DC voltmeter, this voltage was approximately 2.5 V. An AC voltage was produced by the piezoelectric crystal inside the spark knock sensor (KS) whenever spark detonation occurred. This AC voltage was placed on top of the DC voltage. The amplitude of the AC signal, which rode on top of the DC carrier, determined when the PCM would retard spark timing and how long it would keep it retarded.

The new circuit looks the same as the old circuit but acts differently. The new circuit has eliminated the DC carrier voltage. The PCM monitors the circuit only for AC activity. The AC voltmeter normally reads 30 to 50 mV. The voltage produced by the spark knock sensor rises rapidly when spark knock is detected. It remains high until the timing is retarded and the spark knock subsides.

The Generation III V8 uses two spark knock sensors located in the engine block valley underneath the intake manifold. Previous GM's dual-knock sensor engines used a series/parallel circuit. The new engine uses two totally separate knock sensor circuits. Each knock sensor has its own separate power supply. The two knock sensors share no common computer sensor wiring.

The Generation III engine uses a new 32U PCM, which does not require the knock sensor module to be transferred from the previous unit when a new PCM is installed. The knock sensor module is soldered onto the printed circuit board of the new PCM.

Ignition System

The Generation III V8 ignition system is a coil-near-plug system. Eight coil/driver assemblies are mounted on the valve covers. A short high-voltage secondary wire completes the electrical circuit to the spark plugs. This system uses either Denso or Melco coil/driver assemblies on cars; the Delphi coil/driver assembly is used on trucks. The coil/driver assemblies must not be intermixed because of differences in internal current limiters and mounting.

Fuel System

The Generation III engines use a combination of all technologies for the fuel supply system. Trucks use a traditional vacuum-referenced pressure regulator located on the engine's fuel rail. Cars use a semi-returnless system. In this system, the pressure regulator is located inside the fuel filter container (Figure 12–23). The fuel filter container is located outside the fuel tank but in

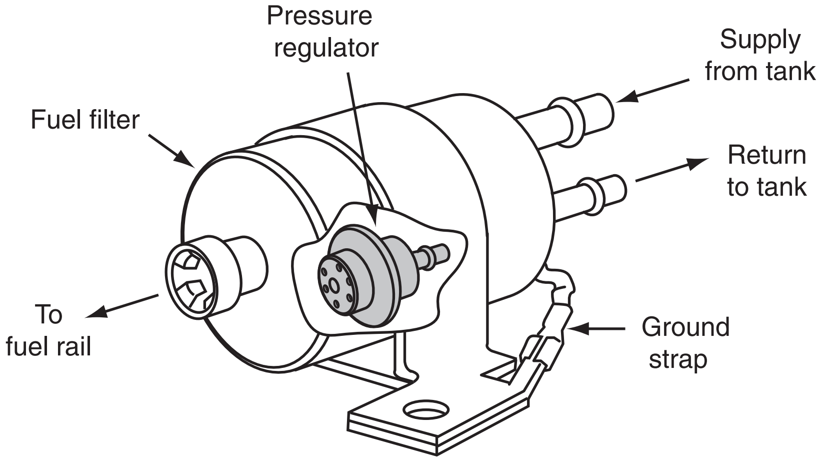


Figure 12–23 Fuel filter with internal pressure regulator.

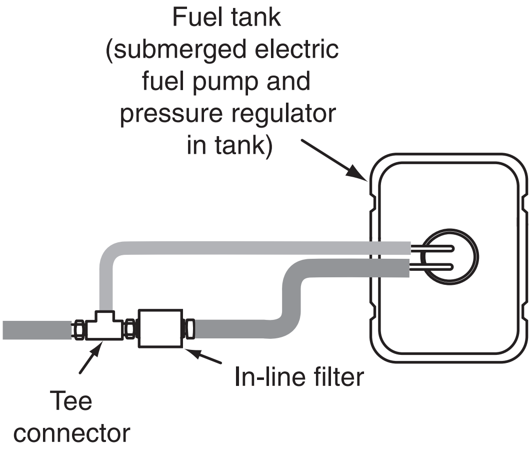


Figure 12–24 Camaro/Firebird fuel tank.

close proximity to it. On some model cars, the fuel pressure regulator may be located inside the fuel tank itself (Figure 12–24).

The *engine coolant overtemp fuel disable* is a new Generation III feature that previously had been used only on the Northstar engine. If the PCM detects a temperature in excess of 270°F, the engine runs on only four cylinders. This allows every other cylinder in the firing order to act as a heat transfer pump. Then the system switches to the next four cylinders. It continues to switch until the engine temperature problem is resolved.

Idle Learn Procedure

Whenever the battery has been disconnected or a new PCM has been installed, the Generation III PCM requires the technician to perform an idle learn. Although the procedures vary for standard and automatic transmissions, the typical idle learn procedure looks like this:

1. Start the engine and let it warm up to a minimum of 176°F.
2. Shift the transmission into drive.
3. Allow the engine to idle for 5 minutes.
4. Turn on the air conditioning.
5. Allow the engine to idle for 5 minutes.
6. Shift the transmission into Park.
7. Allow the engine to idle for 5 minutes.
8. Turn off the air conditioning.
9. Allow the engine to idle for 5 minutes.
10. Turn off the engine for 30 seconds. Restart.

Crankshaft Learn Procedure

In order to increase the accuracy of spark timing on its new Generation III engines, General Motors' technicians must complete a procedure called *crankshaft learn.* The crankshaft learn sequence must be performed whenever the PCM is replaced or reprogrammed. It also must be performed when a component such as the crankshaft, the crankshaft sensor, or the engine block is replaced. Crankshaft learn demands the use of a handheld GM scan tool called the "Tech 2," or its equivalent. The miscellaneous functions menu of the Tech 2 has a crankshaft relearn selection, which leads the technician through a step-by-step process. The procedure goes like this:

1. Wait until the engine has warmed up. The Tech 2 will tell you when you can proceed.
2. Rapidly accelerate the engine to the fuel cutoff point. Tech 2 will identify that speed for you. Release the accelerator pedal when the engine RPM drops.
3. During the coast back to idle RPM, the PCM will learn any variations in the notches cut into the crankshaft reluctor and will store them in the computer's memory.
4. A screen message will appear on the Tech 2 telling the technician that the relearn procedure was successful.

Electronic Throttle Control

Electronic throttle control (ETC) was introduced on the Generation III engines in 1999. Originally called *throttle actuator control* (TAC), this was the first GM application to have it. However, this system is similar to the ETC system introduced on the 2004 Cadillac LH2 and is discussed previously in this chapter. On the Generation III engines, the ETC system was used in the Camaro and Firebird (F body) and Corvette (Y body) vehicles, as well as Chevrolet and GMC (C/K body) light trucks.

GM GENERATION IV SMALL-BLOCK V8S

Introduced on the new 2005 C6 Corvette (the sixth generation of Corvette body types), the new Generation IV V8, also known as the “LS2,” was billed as the “most powerful standard engine ever in Corvette history.” It is a 6.0-L, small-block V8, rated at 400 hp at 6000 RPM and 400 foot-pounds of torque at 4400 RPM. This is an all-new aluminum block with revised oil galleries, an increase in cylinder bore size, and increased camshaft lift. The compression ratio is raised to 10.9:1. “Redline” is increased to 6500 RPM.

The LS2 uses an ignition system with one coil per cylinder, known as a coil-near-plug design. A short spark plug wire is used to connect each coil to its mating spark plug, as on the earlier Generation III engines. The ignition coils are designed to require less current in the primary winding than previous coils but are still able to generate a comparable spark.

The LS2 also has ETC but, unlike the LS1 engine, does not require a separate ETC module. A “smarter” PCM directly controls the throttle plate actuator while receiving input signals from the TPS and APP sensor. This reduces the communication time required and further increases throttle responsiveness.

Another Generation IV engine, known as the “LS7,” was introduced on the 2006 Corvette. At the time of its introduction the LS7 was billed as the largest, most powerful small block ever produced by GM. It is a 7.0-L V8 that puts out 500 hp at 6200 RPM and 475 foot-pounds of torque at 4800 RPM. The LS7 is identified by red engine covers; it is based on Generation IV small-block technology, and therefore it shares much of the technology of the LS2.

GM ACTIVE FUEL MANAGEMENT SYSTEM

Remember the Cadillac 8–6–4 engine of the early 1980s? Well, it is back. Fortunately, though, it is back in a different form due to the fact that electronic technology has advanced greatly during the past 25 years. Active Fuel Management (AFM), formerly known at GM as **Displacement on Demand (DOD),** is designed to increase fuel efficiency while giving the driver full access to the engine’s performance potential. First introduced in 2005 on V6 applications, followed immediately on V8 applications, GM hopes to have two million AFM engines on the road by 2008. Initially, AFM technology will be used on V6 and V8 engines that are put into light trucks and SUVs. The fuel savings is rated at about 8 percent, based on the EPA testing procedure, but is estimated to be as high as 25 percent in certain real-world driving conditions. An early prototype C6 Corvette with an LS2 engine equipped with AFM provided power and acceleration equal to an LS2 without AFM, but fuel mileage was increased from 30 to 35 miles per gallon (MPG).

In actual operation, the AFM system allows the PCM to run a V8 on four cylinders when the need for power is small. Similarly, the V6 is cut to three cylinders when the AFM system kicks in. The engine always starts on all cylinders. When the vehicle is at cruise and the need for power is reduced, the PCM does two things:

1. It turns off the fuel injectors and the spark for one-half the cylinders (four cylinders on the V8 and three cylinders on the V6).
2. It simultaneously closes all intake and exhaust valves on the disabled cylinders, which simply allows the disabled cylinders to act as an air spring (using crankshaft power to compress the trapped air when the piston moves from BDC to TDC, but also returning power to the crankshaft when the piston moves from TDC to BDC). This avoids the energy losses that would occur if the disabled cylinder’s piston were pulling down against manifold

vacuum and pushing out against ambient air pressure on the exhaust side—which are known as “pumping losses.”

A specially designed “switching lifter” is used on the AFM system. It is designed with two portions, an inner body and an outer body, that can physically collapse on each other. (This is similar to the manner in which a shock absorber operates.) A spring is designed as part of the lifter and attempts to keep the lifter extended (Figure 12–25), although this spring has less tension than the valve springs that are used to close the cylinders’ valves. For normal operation, the lifter has a locking pin that keeps the two halves from collapsing on each other; the result is that the cam uses the lifter to open the valve. However, when the PCM wants to disable the valve, it energizes an oil solenoid (Figure 12–26), which provides oil pressure to push the locking pin to “unlock the lifter.” At this point, the lifter collapses on its own spring tension. The spring is strong enough to keep the lifter following the cam lobe but not strong enough to overcome the valve spring tension, thus allowing the valve to stay closed. When the driver punches the throttle, the PCM instantaneously turns the fuel injector back on and de-energizes the oil control solenoid (Figure 12–27). This allows the lifter to expand, allowing the locking pin to lock the lifter in the extended position, and cylinder operation is thereby restored.

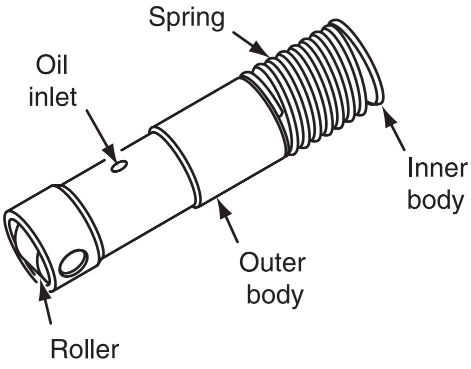


Figure 12–25 A switching lifter from an AFM system.

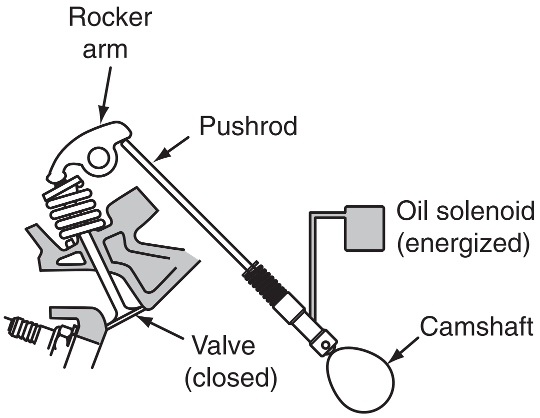


Figure 12–26 Oil solenoid energized and lifter collapsed.

One of the advantages of current AFM technology (as compared to the 8–6–4 system of the early 1980s) is that it is used with ETC technology. When such a system was used without ETC technology, the driver might find that he/she had to compensate slightly at the throttle pedal when the computer disabled or re-enabled cylinders, naturally a cause of concern for the driver. On a modern AFM system with an ETC system, a “smarter” PCM can make this compensation automatically as it disables cylinders or re-enables them. Thus, the driver is able to maintain a consistent throttle

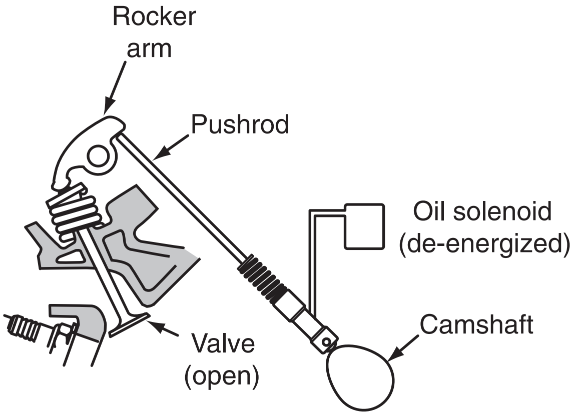


Figure 12–27 Oil solenoid de-energized and lifter extended.

position as cylinders are disabled or re-enabled. In fact, when coupled with an ETC system, the driver will likely be unaware of how many cylinders are actually providing power. This results in fewer driver concerns while enabling a higher degree of fuel economy.

FLYWHEEL ALTERNATOR STARTER SYSTEM

GM 42-V 2004 Silverado Hybrid

In the 2004 model year, General Motors introduced its first vehicle with a 42-V system, a special edition Chevrolet Silverado Hybrid with a Vortec 5.3-L V8. This vehicle is a *dual voltage* vehicle in that it uses neither a straight 42-V system nor a straight 14-V system but rather a combination system that utilizes both voltages. (See Chapter 4 for additional information concerning why a 14-V subsystem will continue to be used with early 42-V system implementation.) The Silverado Hybrid uses what GM calls the **Flywheel Alternator Starter (FAS)** system.

While this vehicle does not technically use an electric motor generator (EMG) to assist the gasoline engine in powering the vehicle's drive train so as to move the vehicle, it does have some fuel-saving features in common with full hybrid drive vehicles—regenerative braking and a transparent engine auto stop/start feature. Thus, this vehicle is considered a mild hybrid.

The Silverado Hybrid is the first production full-size pickup to utilize 42-V/14-V hybrid technology. Its initial availability in 2004 and 2005 was only as a 1500 extended cab model. This is because the extended cab configuration provides a great way to package the energy storage module beneath the rear seat while maintaining passenger comfort. As a 2005 model, its production was limited and, as a result, it was only offered in six states, based upon consumer demand: Alaska, California, Florida, Nevada, Oregon, and Washington. For the 2006 model year the Silverado Hybrid was offered in all 50 states. This mild hybrid was discontinued during the 2007 model year, but GM plans to introduce a full hybrid version of the Silverado as a 2009 model in late 2008. (Full hybrids are discussed further in Chapter 18.)

Silverado Hybrid Components

The primary component in this system, on which everything else is dependent, is the "electric motor generator" (EMG). A "motor/generator" is an electric component that can translate mechanical energy into electrical energy (that is, operate as a generator or alternator does) and can also translate electrical energy into mechanical energy (that is, operate as a starter motor does). The EMG on the Silverado, therefore, replaces both the traditional alternator (generator) and the traditional starter motor. It is located just to the rear of the engine, ahead of the transmission, and outside of a smaller 258-mm torque converter coupled to the engine's flywheel (Figures 12–28 and 12–29). The EMG, sometimes also referred to as the "Electric Machine" (EM), can be used as an electrically driven motor to begin rotating the engine's crankshaft when the engine is to be started. It can also be used as a mechanically driven generator to recharge the system's batteries when the engine is running (driven mechanically by the rotation of the crankshaft) or when the vehicle is coasting or braking (driven mechanically by the drive wheels and drive train). The latter is known as *regenerative braking.* The EMG is capable of producing 7 kilowatts of AC power.

A second component is the energy storage module, a set of three 12.6-V "advanced" lead acid batteries wired in series and located underneath the rear seat (Figure 12–30). (The three batteries wired in series total 37.8 V. When charging system voltage is added, the voltage total is about 42 V.) The energy storage module also contains a cooling fan to help remove heat from the batteries, a 400-amp fuse, and an energy storage control module (ESCM), which provides automatic shutoff in certain instances to help protect the system.

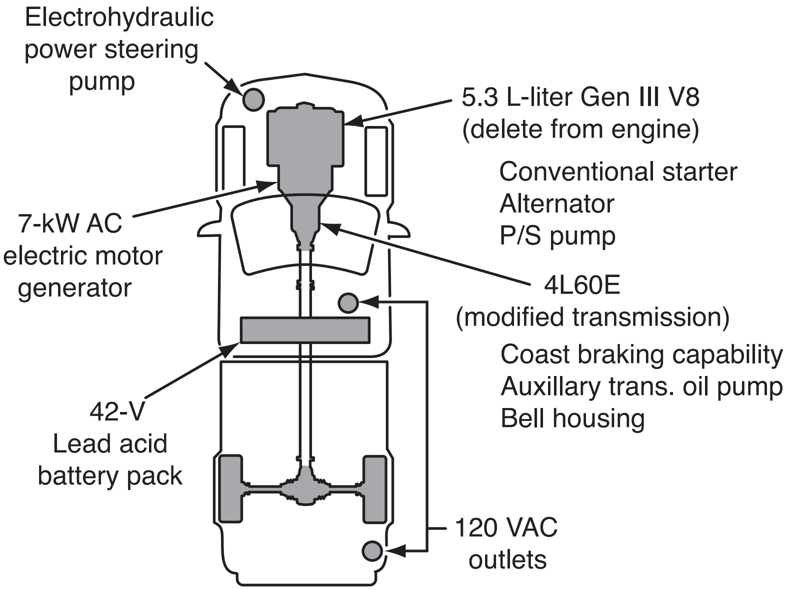


Figure 12–28 Silverado Hybrid vehicle overview.

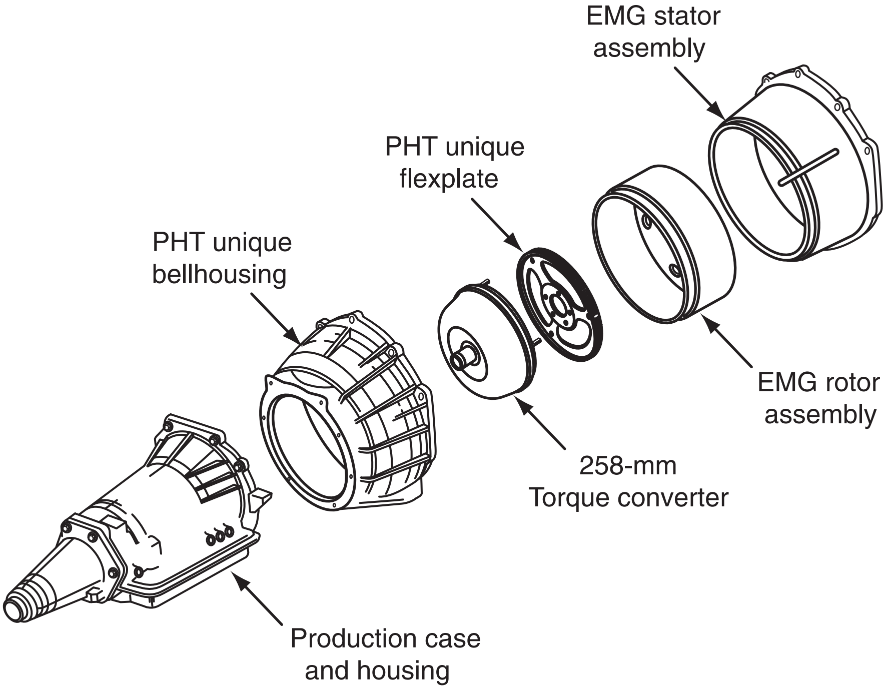


Figure 12–29 Transmission and EMG assembly.

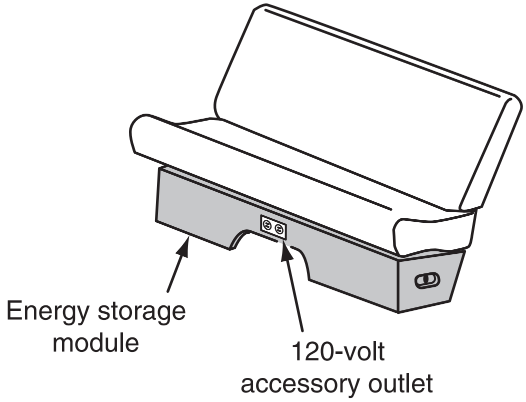


Figure 12–30 Rear seat showing part of the energy storage module. Also note the 120-V accessory power outlet (APO) on the lower portion.

A third component is the starter/generator control module (SGCM), located in the engine compartment. This unit manages the vehicle's electric power by taking starter/generator-supplied 42-V alternating current (AC) power and converting it into three different forms of power as follows (Figure 12–31):

1. 42-V direct current (DC) to charge a 42-V battery.
2. 14-V DC to charge a 14-V battery and operate the vehicle's 14-V subsystem.
3. 120-V AC to power four 120-V AC power points, each referred to as an accessory power outlet (APO). Two of these APOs (a normal household double wall outlet) are located in the right rear of the truck's bed. Two additional APOs are located underneath, but to the forward side, of the rear seat (Figure 12–30). All four APOs can collectively supply 2400 watts of 120-V AC power.

Increased Fuel Mileage

The Silverado Hybrid combines intelligent computers with regenerative braking to give this vehicle a substantial increase in fuel economy. The regenerative braking ability of the EMG means that braking energy (which is turned into waste heat on traditional vehicles) is now translated into electrical energy to recharge the system's 42-V energy storage module.

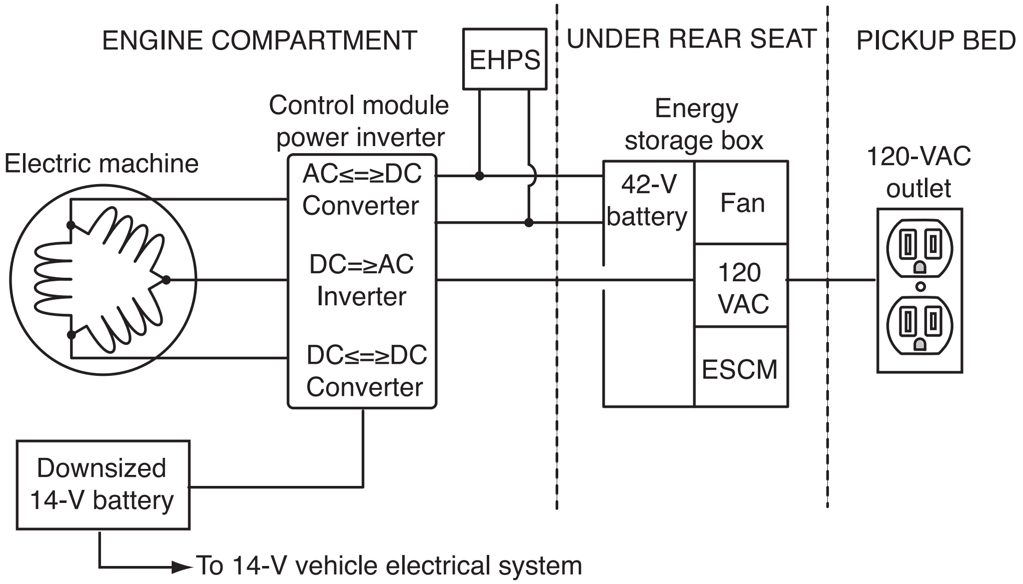


Figure 12–31 Silverado Hybrid system overview.

This vehicle also features an engine start/stop system that automatically shuts off the engine to save fuel when the driver is braking at speeds below 13 mph. The engine also shuts off when the vehicle is not moving. When the driver releases the brake pedal and pushes on the throttle to re-accelerate from a stop or deceleration (or if the "Tow/Haul" button has been pressed), the engine begins to run again. Because the EMG uses no gears (due to the fact that it is designed to operate at 42 V), the EMG is able to begin turning the engine's crankshaft without the audible gear whine that would be associated with a traditional starter motor. As a result, the restart of the engine is almost transparent to the driver.

Another energy-saving feature is the electro-hydraulic power-assist steering system. This system uses a 42-V electric motor to drive the hydraulic power steering (P/S) pump, thus eliminating the tradition belt-driven pump. As a result, the power assist can be reduced, or even turned off, as driver demand dictates, thereby saving energy compared to a belt-driven pump that requires continual energy usage.

The collective result is an average fuel economy increase of 2 MPG in city driving with no loss of power (when compared to the traditional Vortec 5.3-L V8 in a similar truck). Estimated fuel economy on the two-wheel-drive model is 18 MPG city and 21 MPG highway, and on the four-wheel-drive model it is 17 MPG city and 19 MPG highway, based on GM's testing (no official EPA estimate is yet available). This amounts to about a 13 percent increase in fuel economy.

APO Operational Modes

The APOs, located under the rear seat and also at the right rear of the truck's bed, can provide a combined 2400 watts of 120-V AC power. Each outlet is protected by a 20-amp fuse and has ground fault protection. An APO switch mounted on the instrument panel is used to activate the outlets.

The APOs operate in two modes. Normal mode is used while the vehicle is being driven. The driver simply presses the APO switch and waits for an APO indicator to light. The power outlets can then be used until the APO switch is pressed again or until the ignition switch is turned to off. Continuous mode operation allows the 42-V energy storage module, combined with the 5.3-L engine and the EMG, to function as a generator when the vehicle is stationary. The transmission must be in park for this mode to operate. (The key does not need to be in the ignition, however.) The engine will automatically run only as needed to help the 42-V energy storage module provide the 120 V of AC power. This mode activates the horn relay if the level of fuel in the tank gets too low. If the low-fuel warning goes unheeded for 5 minutes, the APO system automatically shuts down to avoid completely emptying the fuel tank.

General Motors' Approach to Fuel Savings Technology

While many other manufacturers are applying their hybrid drive technology, fuel cell technology, and other technologies designed to increase fuel mileage to smaller vehicles such as the Honda Civic and the Toyota Prius, GM's engineers are, instead, applying the "fuel saving" technologies to their larger vehicles with the V6 and V8 engines. These are the vehicles that many consumers want to purchase and drive—the people-mover SUVs and minivans, the workhorse pickup trucks, and even the larger passenger cars. Certainly one primary concept here is to increase the fuel economy on the vehicles that ordinary people drive (as opposed to competing to see how much mileage can be gotten out of the smallest cars). But

(*continued*)

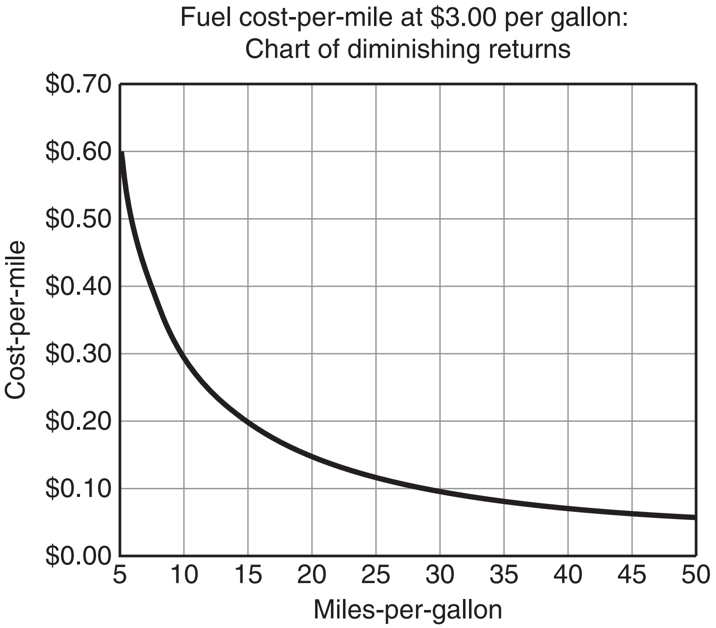


Figure 12–32 Fuel costs-per-mile chart.

another concept involves the "Chart of Diminishing Returns" (Figure 12–32) concerning fuel economy.

If you study this chart, you will see that at a cost of $3.00 per gallon of gasoline applied to a vehicle that gets 10 MPG, the vehicle's cost-per-mile is 30 cents per mile. If you were to double this vehicle's fuel mileage to 20 MPG (an increase of 10 MPG), you would cut the cost in half to 15 cents per mile and therefore experience a savings of 15 cents per mile. You can never again save another 15 cents per mile, as that would reduce the cost to zero.

If you again double this mileage to 40 MPG (an increase required this time of 20 MPG), you cut the 15 cents per mile cost in half to 7½ cents per mile—a savings this time of only 7½ cents per mile. And you would have to double this again to 80 MPG (an increase of 40 MPG—not easy to accomplish) to save another 3.75 cents per mile.

This chart actually curves from substantial savings for every small increase in fuel mileage when the mileage is less than around 18 to 20 MPG to very little increase in savings when the mileage is above 30 MPG. The chart also works, showing the same curve, for any cost per gallon, whether it is $1.00 per gallon, $2.00 per gallon, $3.00 per gallon, $4.00 per gallon, or more.

Therefore, if a vehicle is achieving less than around 20 MPG, it becomes quite profitable to get an additional one or two MPG increase out of the vehicle as new technologies are applied. The same mileage increase applied to a small car that already achieves 38 MPG is not nearly as cost effective. No wonder GM is targeting the larger vehicles with their newest technologies.

BELT ALTERNATOR STARTER SYSTEM

GM 42-V 2007 Saturn VUE and 2008 Chevrolet Malibu

GM introduced another hybrid technology, known as the **Belt Alternator Starter (BAS)** system, on the 2007 Saturn VUE and on the 2008 Chevrolet Malibu. This system, like the FAS used on the Silverado Hybrid, uses a 42-V electrical system in combination with regenerative braking and a transparent engine auto stop/start feature. The BAS system is also used in conjunction with an ETC system.

What makes this system different is that the EMG that constitutes both the starter and the alternator is not designed as part of the transmission's torque converter as on the Silverado Hybrid. Rather, this 36-V motor and alternator assembly mounts in line with the crankshaft's pulley, much as a traditional alternator. It has a belt that allows it to either be belt-driven by the crankshaft or to drive the crankshaft.

With the gasoline engine running, the EMG operates as a belt-driven alternator producing 42 V to charge the 36-V battery. And, following an auto stop function during deceleration or braking, the EMG acts as a 36-V starter, using the belt to turn the crankshaft until the engine is running again. As a result, the incorporation of this design allowed the engineers to add the BAS system to 4-cylinder and 6-cylinder engines with minimal changes to the engine and transmission, unlike the FAS system used on the Silverado Hybrid, which required an extensive redesign of the transmission's torque converter.

The auto start/stop feature will not function when the transmission is in "park." Neither will it function after an initial engine start but before the vehicle has been driven. Therefore, when starting the engine with the transmission in "park," a traditional 12-V starter is used to turn the crankshaft. But, once the engine is running, the transmission has been shifted into "drive," and the vehicle has been driven, the BAS system performs the following functions:

- Auto stop/start feature: During deceleration and braking, the BAS system cuts the fuel to the engine, resulting in engine stall. As the driver operates the accelerator pedal position (APP) sensor so as to accelerate again, the computer responds by using the alternator/starter to start the engine again.
- Regenerative braking: The BAS system uses regenerative braking during deceleration or braking to cause the alternator/starter to use the vehicle's mechanical energy to charge the 36-V battery.
- Electrical power assist: The BAS system allows the alternator/starter to provide some electrical power assist during periods of high engine load. While the BAS system operates at a low voltage compared to a full hybrid vehicle, the vehicles that it is used on are also smaller than the Silverado Hybrid, thus allowing the 36-V motor to be more effective in its ability to assist the gasoline engine than on a heavier vehicle.

The vehicles with the BAS system are designed to achieve a fuel mileage increase of about 16.5 percent, which breaks down as follows:

- auto stop/start: 4 percent
- deceleration fuel cutoff: 3.5 percent
- regenerative braking: 1 percent
- increased efficiency of engine and transmission: 4.5 percent
- improved aerodynamics: 0.5 percent
- ultra-low rolling resistance tires: 3 percent

Ultimately, this mild hybrid offers a fair gain in fuel economy at an attractive price, thus making these vehicles an excellent value.

WARNING: When working on or around any hybrid, always remove all jewelry, including rings, watches, and necklaces.

This does include mild hybrids with batteries rated at 36 V and a charging system that operates at 42 V. A short to ground in a 42-V system can produce an arc that is between 50 and 100 times hotter than the same short to ground in a 14-V system.

GM VOICE-RECOGNITION/ NAVIGATIONAL SYSTEM

General Motors (GM) introduced a combination voice-recognition/navigational system on 2004 Cadillac SRX and XLR models. For model year 2005, this system is added to the Cadillac STS. For model year 2006, it is added to the Cadillac DeVille and the new Buick Lucerne. The system allows the driver to press a button labeled "VOICE" on the steering wheel that activates a voice-recognition system for issuing commands to the navigational system.

By itself, the navigational system is a mapping system, similar to a "streets and trips" program that you might install on a PC. Such a program can quickly choose the best route between two points on a map. For example, if you enter your current position as your home address and then enter another address to which you wish to travel, the program will quickly give you turn-by-turn instructions for getting to your destination. As a navigational system on a vehicle, the system's control module uses the Global Positioning System (GPS) to determine the vehicle's current position, heading, and speed. The driver can use either a text entry (if the vehicle is stopped) or a voice entry to enter a desired destination, either an address or a point of interest. Points of interest that are programmed into the system include restaurants, gas stations, and ATMs.

Voice entry of a desired destination is achieved by depressing the voice button on the steering wheel and then speaking the desired destination address or point of interest aloud. If, after depressing the voice button, the driver says, "I'm hungry," the navigational system will display restaurants, from which a specific type of food or restaurant chain can be chosen. Additionally, the voice-recognition system's control module is multiplexed to other computers on the vehicle (see Chapter 9). If, after depressing the voice button, the driver says, "Roll the windows up," the message is sent to the relevant control module and the windows will be closed.

✔ SYSTEM DIAGNOSIS AND SERVICE

WARNING: These vehicles are equipped with safety air bags. Any technician working on or around the circuits involved in the air bag system should review the relevant sections in the service manual before performing any service on the vehicle. Failure to do so can result in personal injury from unexpected air bag deployment, as well as expensive damage to the vehicle.

The first step in any problem diagnosis is a careful visual inspection. As mentioned, one of the most important points of this inspection is to check for grounds for the engine and the computer. Familiarize yourself with those locations (they vary with the vehicle) and learn to use the voltage drop test to check for resistance. While checking for grounds is often described, as here, as a visual inspection, it is, of course, nothing of the sort. Use voltage-drop measurements to make these checks.

Many intermittent problems are the result of poor ground connections. Check for leaking vacuum lines, loose connectors, and each of the ordinary problems that might disable any vehicle, computer controlled or not. Check for damaged or collapsed air ducts, as well as air leaks around the throttle body or sensor mating surfaces. Check the spark plug cables for cracks, hardness, proper routing, and continuity. Most problems should be discovered in the course of a visual inspection.

Check that the PCM and MIL lights are working properly. They should come on with the ignition switch as a bulb check. The next step is to check for stored DTCs. Connect a scan tool to the DLC (which is supposed to be visible from a squatting position at the driver's door). Following the instructions on the tool, read out any stored DTCs and record them.

Make sure the engine is at a comparatively low temperature. The Northstar engines include a feature, called *engine metal overtemp mode,* whereby at temperatures above 270°F the PCM will selectively disable four of the cylinders at a time to keep the engine temperature from reaching destructive levels. This injector disabling will be felt by the driver as a loss of power and roughness, of course. Verify the customer complaint and compare the stored codes to those found in the appropriate section of the manual.

The PCM includes a snapshot feature that records all the relevant sensor and actuator states at the time of any recorded fault. Often this stored information will point to the cause of the problem. The scan tool can also call up the freeze frame or failure records data for intermittent problems.

Diagnostic & Service Tip

While the PCM on these systems has become much more complex than earlier, simpler engine control computers, it has also become much more reliable. Despite the widespread belief that almost any driveability problem is caused by "the computer," in fact, the PCM itself is very rarely the cause of driveability or emissions problems. Even when the trouble codes indicate something in the computer, it is important to check the ground circuits for the computer and the engine itself. Because of the very low-current/low-voltage signals used for these components, checking voltage drop rather than resistance is a much more revealing test when trying to eliminate problems. All ohmmeters are of questionable accuracy as they approach zero resistance, but voltmeters remain quite accurate even down to millivolts. Learn how to substitute voltage-drop tests for resistance tests if you plan to do successful work on engine control computers.

SUMMARY

In this chapter we presented an overview of the various versions of the Northstar engine, its applications, and its features. We looked at the Northstar's inputs and outputs, including the dual-range ECT sensor. We discussed the ability of the Northstar's PCM to disable cylinders selectively to allow a driver to get the vehicle to a repair facility when the engine has overheated. We also discussed the waste spark and coil-on-plug (COP) ignition systems used on the Northstar. And we took an in-depth look at some of the newest systems to be added to the Northstar engine: the variable valve timing (VVT) system used to modify the cam timing of all four camshafts and the ETC system that eliminates the mechanical throttle cable and increases the engine's responsiveness. The ETC system also eliminates the need for the speed control servo and the idle air control (IAC) actuator; it also provides the PCM a direct means for reducing engine torque when the traction control system must be activated. We also briefly discussed the keyless access system used on the Cadillac XLR.

This chapter also addressed the new Global V6, known as the High Feature V6 (HFV6), introduced on the 2004 Cadillac CTS and 2005 STS. We discussed many of the features associated with this engine.

This chapter also looked at the GM small-block V8 and gave the reader an overview of the Generation II and Generation III versions of this engine. Then the systems used on the Generation III engines were discussed in some depth. We also introduced the Generation IV version of this engine.

Finally, we completed this chapter with an in-depth discussion of three new-technology systems designed to increase fuel economy that GM is now offering: The AFM system introduced initially on light truck and SUV engines for the 2005 model year; the 42-V/14-V FAS system that GM introduced on the 2004 Chevrolet Silverado Hybrid; and the 42-V/14-V BAS system that GM introduced on the 2007 Saturn VUE and on the 2008 Chevrolet Malibu. We also discussed the combination voice-recognition and navigational system that GM introduced in the 2004 model year.

▲ DIAGNOSTIC EXERCISE

A vehicle with the Northstar engine is brought into the shop with much reduced power shortly after start-up. All three oxygen sensors report a lean mixture, though the spark plugs are all black with carbon. Even before you pull the OBD II codes, what kinds of problems could cause these symptoms?

Review Questions

1. Technician A says that a person can feel a static discharge of about 4000 V or more. Technician B says that an electronic component, such as a computer's memory chip, can be damaged by a static discharge of as little as 100 V. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. Technician A says that modern PCMs have a more advanced learning capacity than previous PCMs did. Technician B says that disconnecting the battery will always erase all of the learned data from a modern PCM's memory. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
3. On a Northstar application, if the PCM senses that a front drive wheel has lost traction, it may individually apply the brakes at one wheel to regain traction. In extreme cases, it may also reduce engine torque by disabling up to seven of the fuel injectors *except* under which of the following conditions?
   A. When the engine coolant temperature is below –40°F
   B. When the engine coolant level is low
   C. When the engine speed is below 600 RPM
   D. All of the above
4. A Northstar engine in a vehicle is started cold and is then allowed to warm. The ECT sensor voltage is being monitored. While the engine is warming, the voltage is decreasing. Then the voltage suddenly increases. Technician A says that this indicates that the ECT sensor is faulty and should be replaced. Technician B says that this indicates that the PCM is faulty and should be replaced. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
5. If the PCM detects cylinder misfire on an OBD II Northstar application, it will do which of the following?
   A. Shut off the fuel injector for the misfiring cylinder
   B. Keep the injector energized for the misfiring cylinder
   C. Turn off the spark for the misfiring cylinder
   D. Retard spark timing for the misfiring cylinder
6. On a Northstar application, the PCM will set a code in memory if the power steering pressure switch is open and vehicle speed is in excess of which of the following speeds?
   A. 10 mph
   B. 25 mph
   C. 30 mph
   D. 45 mph
7. On a Northstar application, if the PCM sets an EEPROM defect code in memory, what must the technician do?
   A. Replace the EEPROM
   B. Replace the PCM
   C. Reset the EEPROM by disconnecting the vehicle battery for 10 minutes
   D. Reset the EEPROM by removing it from the PCM, then reinstalling it
8. How is the Generation III/IV V8 ignition system designed?
   A. It uses a distributor to distribute spark from a single ignition coil to each of the spark plugs.
   B. It is a waste spark ignition system that uses four ignition coils.
   C. It uses eight ignition coils placed on top of the spark plugs to eliminate the secondary ignition wires.

   D. It uses eight ignition coils placed near the spark plugs and uses secondary ignition wires.

9. What is meant by the term "close-coupled catalytic converters"?
   A. The NO_x reduction bed is located immediately downstream of the CO/HC oxidizing bed.
   B. The catalytic converters are mounted directly adjacent to the exhaust manifolds.
   C. The NO_x reduction bed is located immediately upstream of the muffler, and the CO/HC oxidizing bed is located immediately downstream of the muffler.
   D. The CO/HC oxidizing bed is located immediately upstream of the muffler, and the NO_x reduction bed is located immediately downstream of the muffler.
10. What is the VVT system on the LH2 Northstar engine designed to do?
    A. Vary the cam timing of both exhaust camshafts only
    B. Vary the cam timing of both intake camshafts only
    C. Vary the amount of valve lift and duration for the 16 exhaust valves
    D. Vary the cam timing of all four camshafts (both exhaust camshafts and both intake camshafts)
11. Regarding the addition of an ETC system to an engine, which of the following statements is *false?*
    A. An ETC system is less responsive than a mechanical throttle cable.
    B. The throttle cable is eliminated.
    C. The speed control servo is eliminated.
    D. The IAC stepper motor is eliminated.
12. What is the function of the keyless access system used on the Cadillac XLR?
    A. It allows a person to enter the vehicle using a five-button keypad located on the driver's door.
    B. It allows a person who has lost the vehicle's keys/key transmitter to enter the vehicle and start the engine through a voice-recognition program.
    C. It allows a person who has lost the vehicle's keys/key transmitter to enter and start the vehicle through fingerprint recognition.
    D. It allows a person who has the vehicle's keys/key transmitter on their person to enter the vehicle and start the engine without having to put a key physically into the door lock cylinder or the ignition lock cylinder.
13. The HFV6 3.6-L engine that was introduced in Cadillac models beginning in 2004 uses oil squirters to douse the bottom of the pistons and surrounding cylinder wall. What is the primary purpose of this design?
    A. To provide additional lubrication for the piston rings
    B. To help the rings seal with the cylinder wall
    C. To help cool the pistons
    D. To squirt a fraction of this oil past the rings and into the combustion chamber
14. How does a General Motors AFM system respond when the need for power is reduced?
    A. The PCM disables the spark for one-half of the cylinders and allows the associated valves to continue to operate so the engine can pump air through these cylinders.
    B. The PCM disables the fuel injectors for one-half of the cylinders and allows the associated valves to continue to operate so the engine can pump air through these cylinders.
    C. The PCM turns off the fuel injectors for one-half of the cylinders holds the associated valves open.
    D. The PCM turns off the fuel injectors and spark for one-half of the cylinders and closes the associated valves.
15. What other technology is used to help enable the success of a modern AFM system?
    A. ETC
    B. VVT
    C. 42-V
    D. Engine metal overtemp mode
16. How many AFM engines does General Motors hope to have on the road by 2008?
    A. 10,000
    B. 100,000

   C. 2,000,000
   D. 5,000,000

17. On the Chevrolet Silverado Hybrid, all *except* which of the following statements are true?
   A. The EMG replaces the traditional starter motor.
   B. The EMG replaces the traditional alternator.
   C. The 42-V system is used to power an electromagnetic steering assembly that uses no hydraulic assist.
   D. Regenerative braking is used to recharge the system's batteries.

18. A carpenter is using the Silverado Hybrid at a construction site. He has an electric saw plugged into the APO at the right rear of the truck's bed. The APO system is in continuous mode. Suddenly, he hears the truck's horn. What is indicated?
   A. The fuel level in the fuel tank is low.
   B. The system's batteries are almost dead.
   C. The system's batteries are overcharged.
   D. The electric saw is drawing too much current.

19. Which of the following is the most reliable method of testing the PCM's power and ground circuits?
   A. Use a test light to test circuit continuity.
   B. Use a logic probe to test circuit continuity.
   C. Use an ohmmeter to measure each circuit's resistance.
   D. Use a DVOM to test voltage drop across each circuit.

20. Technician A says that when working on or around the circuits that control safety air bags, a technician should first review the air bag sections in the service manual before performing any service work on the vehicle. Technician B says that an unexpected air bag deployment can result in personal injury. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

Chapter 13

Ford's Electronic Engine Control IV (EEC IV)

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

☐ Describe the major aspects of the EEC IV PCM.
☐ Understand the operating modes that pertain to the EEC IV PCM.
☐ Define the inputs associated with an EEC IV system.
☐ Define the outputs under the control of the EEC IV PCM.
☐ Describe the basic operation of an Integrated Vehicle Speed Control (IVSC) system.
☐ Understand the proper approach to system diagnosis and service on an EEC IV–equipped vehicle.

KEY TERMS

A4LD (Automatic Four-Speed Light-Duty) Transmission
Adaptive Strategy
AXOD (Automatic Transaxle Overdrive)
Capacitor
Diagnostic Routines
EGR Control (EGRC)
EGR Vent (EGRV) Solenoids
Engine Calibration Assembly
Inertia Switch
PIP Signal
Quick Test
SPOUT
Star Tester
Thick Film Integrated (TFI-IV)
Torque Converter Lockup Clutch

Ford Motor Company's Electronic Engine Control IV (EEC IV) system is the fifth generation of Ford's computerized engine control systems, following EEC I, EEC II, EEC III, and MCU (Microprocessor Control Unit). It was first introduced in late 1982 on limited 1983 applications. By 1985, the EEC IV system was the only computerized engine control system that Ford was using except for some fleet packages (taxicab and police vehicles) that continued to use the MCU system as late as 1991. By the 1986 model year, all Ford, Lincoln, and Mercury passenger cars had the EEC IV system except the Ford Escort and Mercury Lynx, which did not get the system until the 1987 model year, when they also became equipped with the single-point fuel injection system. By the 1987 model year, all Ford light trucks (Ranger, Bronco, Bronco II, F-series, and E-series) had the EEC IV system on 2.3-L, 2.9-L, 4.9-L, and 5.0-L engines, except for the two largest light truck engines, the 5.8-L (351 CID) and the 7.5-L (460 CID), which still had non-feedback Holley carburetors. These engines were equipped with the EEC IV system and a multipoint fuel injection system in the 1988 model year. By the 1988 model year, all of Ford's major model lineups were equipped with the EEC IV system, with only a few exceptions, such as low-altitude Rangers equipped with a 2.0-L engine. The EEC IV system began to be replaced by the OBD II–compliant EEC V system in the 1994 model year, but EEC IV continued to be used as late as the 1996 model year (F150). Use of the EEC IV system spanned a total of 14 years, from 1983 through 1996.

The EEC IV system is a full-function system, controlling air/fuel ratio, idle speed, ignition timing, and emission systems, as well as electronic transmission performance and torque converter clutch lockup. The *primary* job of the EEC IV system is to control the air/fuel ratio. This is achieved through a feedback carburetor, a single-point fuel injection system, or a multipoint fuel injection system.

When used with a feedback carburetor, the EEC IV powertrain control module (PCM) controlled a normally closed solenoid on a duty cycle, which, in turn, controlled an air bleed to the main metering and idle circuits of a Motorcraft or Carter carburetor. On one Holley feedback carburetor design, the PCM controlled a duty cycle solenoid that, in turn, controlled a vacuum signal to the carburetor's power valve diaphragm.

The single-point fuel injection design used either one or two fuel injectors that were mounted in a throttle body. While Ford Motor Company refers to this system as Central Fuel Injection (CFI), it is equivalent to what other manufacturers call Throttle Body Injection or TBI. A CFI throttle body unit is shown in Figure 13–1.

Ford refers to the multipoint fuel injection system as Electronic Fuel Injection (EFI). An EFI fuel rail assembly is shown in Figure 13–2. In 1985, Ford also introduced a sequentially injected version of EFI known as Sequential Electronic Fuel Injection (SEFI). These engines were labeled (typically on the valve cover) as being equipped with a SEFI system.

In this chapter, the emphasis will be on the CFI, EFI, and SEFI applications. Figure 13–3 shows the typical inputs and outputs associated with an EEC IV computer system.

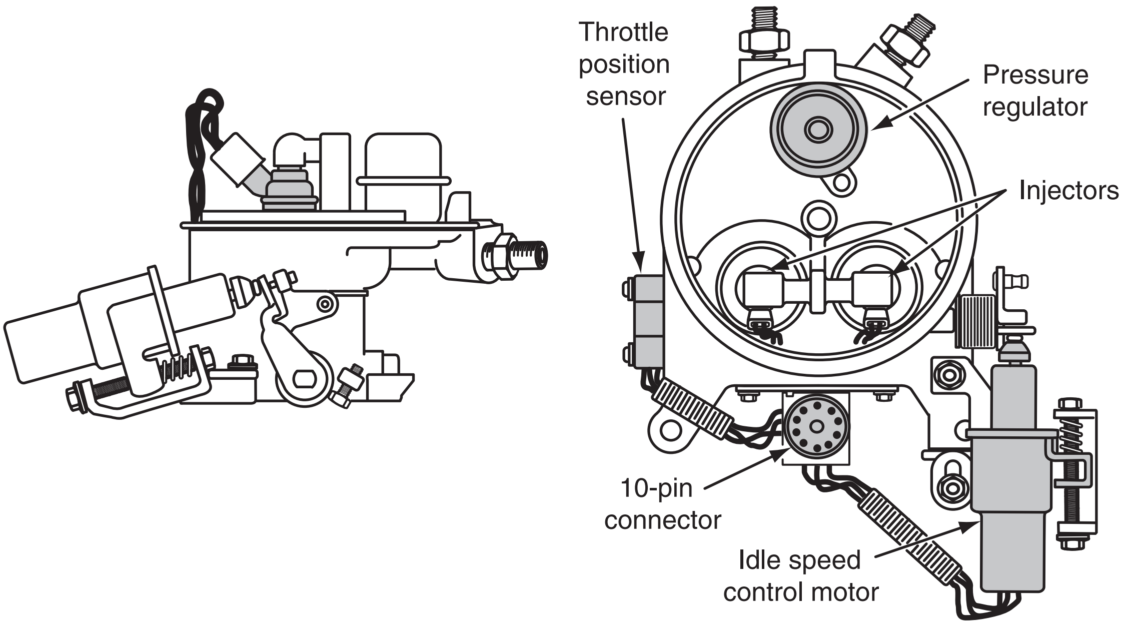


Figure 13–1 CFI unit.

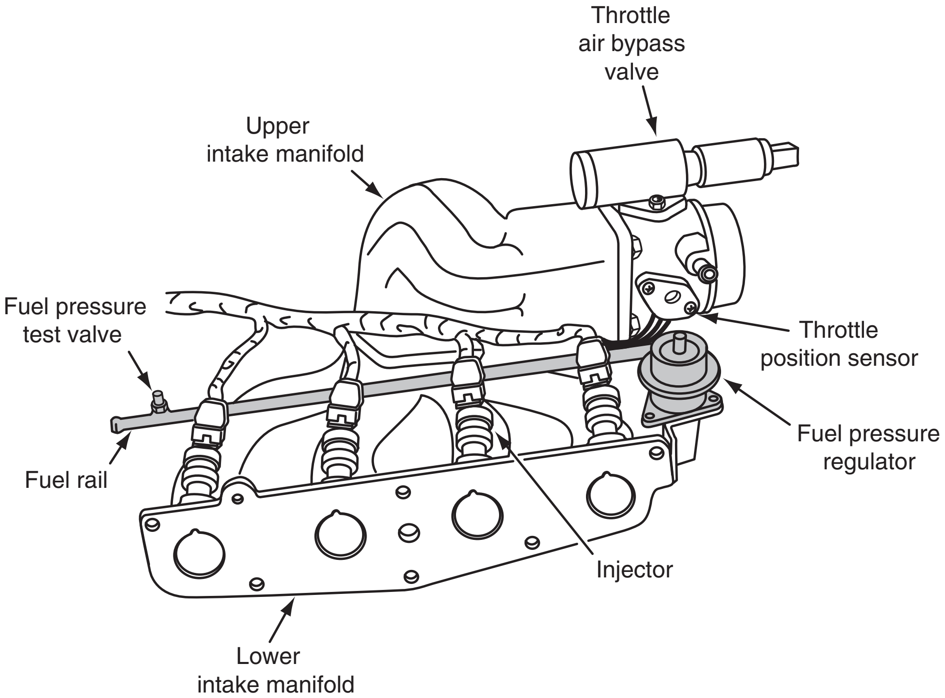


Figure 13–2 Multipoint EFI manifold (1.6 L).

Inputs

Engine coolant temperature
Manifold absolute pressure and/or barometric pressure
Throttle position
Engine speed and crankshaft position
Exhaust gas oxygen
EGR valve position

The following sensors are unique to specific engines:

Air charge temperature
Vane air temperature
Vane airflow
Idle tracking switch
Transmission position
Inferred mileage sensor
Knock sensor
Ignition diagnostic monitor
Clutch engaged switch
Brake on/off switch
Power steering pressure switch
Air-conditioning clutch
Ignition switch

Powertrain
Control
Module
(PCM)

Power
Relay

Outputs

Air/fuel mixture control device, carburetor solenoid or injector
Ignition timing control
Idle speed control
Thermactor airflow control
Canister purge control
EGR flow control
Torque converter clutch control
Turbocharger boost control
A/C and cooling fan controller module
Wide-open throttle A/C cut-off
Inlet air temperature control
Variable voltage choke
Temperature-compensated accelerator pump
Shift indicator light
Fuel pump relay

All components are not used on any one system.

Figure 13–3 EEC IV system overview.

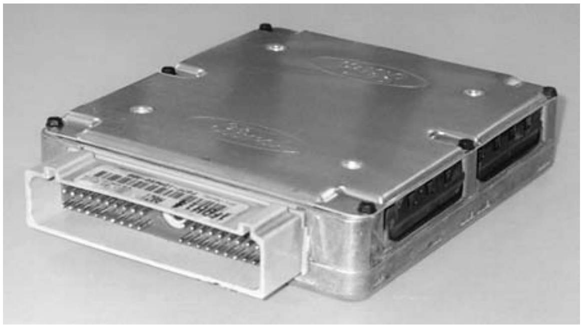


Figure 13–4 EEC IV PCM.

POWERTRAIN CONTROL MODULE

The EEC IV system computer, known under OBD II standards as the PCM, was known prior to OBD II standardization as the Electronic Control Assembly (ECA). It has considerably more capacity than previous Ford engine control computers (Figure 13–4). It is the first to include a keep-alive memory (KAM) (an expansion of its hardwired random-access memory), enabling it to store codes related to faults that it has previously observed but that are no longer present. (This capacity did not exist in the first application of EEC IV on the 1.6-L engine.) The number of codes it can recognize is greatly increased compared to the computers in earlier Ford systems.

Engine Calibration Assembly

The PCM's **engine calibration assembly** contains the necessary programming to fine-tune the PCM's commands to the specific needs of the vehicle and engine's weight, axle ratio, and transmission. The calibration assembly is similar to a GM PROM, except that unlike those systems' unit, the Ford calibration assembly is an integral part soldered into the PCM, and it cannot be removed or serviced separately.

OPERATING MODES

The PCM controls the engine in one of several operational modes or strategies.

Base Engine Strategy

The PCM uses this mode to control warm engine calibration through the wide range of operating conditions occurring in normal driving. Prior to 1986, the criterion for warm engine operation was a coolant temperature of 190°F (88°C) or higher. To reduce the time spent running in open-loop conditions, that threshold was lowered in 1986 to about 130°F (54°C) or higher. This warm-up mode is divided into four sub-modes:

1. cranking
2. closed-throttle operation
3. part-throttle operation (closed loop)
4. wide-open throttle (WOT)

Input information enables the PCM to recognize these operational modes. Once it recognizes the state of the engine (the operational mode), the PCM issues calibration commands to the appropriate actuators, commands designed to produce the best results in terms of emissions, fuel economy, and driveability.

If the engine threatens to stall while in the base engine strategy mode, the PCM will employ an under-speed response feature.

MPG Lean Cruise

When predetermined criteria are met during cruise conditions on some engine applications (beginning in 1988), the PCM takes the system out of closed loop to an even leaner "dead-reckoning" (no feedback) open-loop air/fuel ratio. The purpose of this modification is to achieve better fuel economy.

Modulator Strategy

Operating conditions requiring significant compensation to maintain good driveability cause the PCM to modify the base engine strategy. Conditions causing such modifications are:

- cold engine
- overheated engine
- high altitude

Limited Operational Strategy (LOS)

When a component failure prevents the system from functioning in a normal strategy, the PCM enters an alternative strategy designed to protect other system components, such as the catalytic converter, yet still provide enough driveability to keep the vehicle running until it can be repaired. If the PCM's central processing unit (CPU) fails, the PCM will operate in a fixed mode: There will be no spark advance, no EGR, and air from the Thermactor system (Ford's air injection system) will be dumped to the atmosphere.

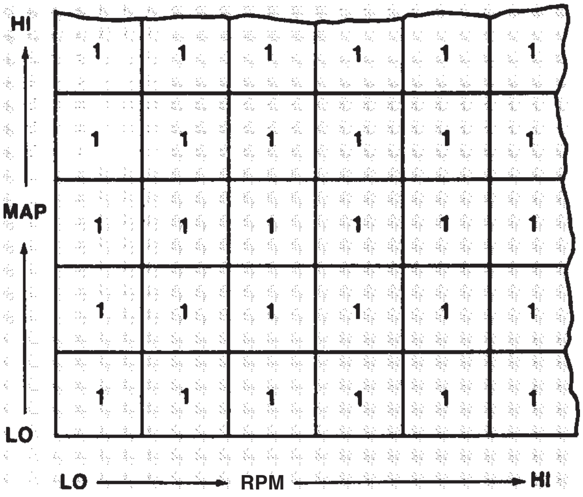
Adaptive Strategy

This feature, first introduced in 1985, enables the PCM to constantly adjust some of its original calibrations, those programmed into it by engineers based on ideal conditions. Whenever conditions are less than ideal, due to variations in manufacturing tolerances, wear, or deterioration of sensors or other components that affect the PCM's control of the most critical functions, the **adaptive strategy** puts an adjustment or adaptive factor into the calculation process. Adaptive strategy could also be called a learning capacity or a self-correction ability. The PCM learns from past experience so it can better control the present conditions. Learning starts when the engine is warm enough to go into closed loop and is in a stabilized mode.

Adaptive Fuel Control. This adaptive strategy concerns air/fuel ratio. If the injectors become fouled with deposits or if wear in the pressure regulator causes a slight loss of fuel pressure, the result is less fuel injected into the cylinder than there should be during the pulse width the computer has calculated for the conditions. When the system is in closed loop, the oxygen sensor reports a lean condition to the PCM. The PCM responds by commanding a wider injector pulse width to maintain the proper 14.7:1 air/fuel ratio.

The adaptive fuel control recognizes that a wider pulse width than that which the original calibration designated is required. If this condition continues for several minutes, the adaptive fuel control modifies the original calibration to provide a wider pulse width so the calibration is more on target and less correction is needed to bring the mixture to stoichiometry. Notice that all forms of adaptive strategy, or learning, are in response to signals from the oxygen sensor.

How the Calibration Modification Is Achieved. The ROM (read-only memory, the hardwired original set of computer instructions) contains an electronic look-up table that compares engine load (manifold absolute pressure [MAP] sensor signal) and engine RPM; this table is used as the starting point for calculating pulse width (Figure 13–5). The table is divided into separate cells. Each cell is assigned a base value of 1. Cross-referencing the current MAP value with the current RPM value, the microprocessor identifies the cell that best represents current engine load and speed conditions. The value in that cell is used as a multiplier in the microprocessor's



1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1

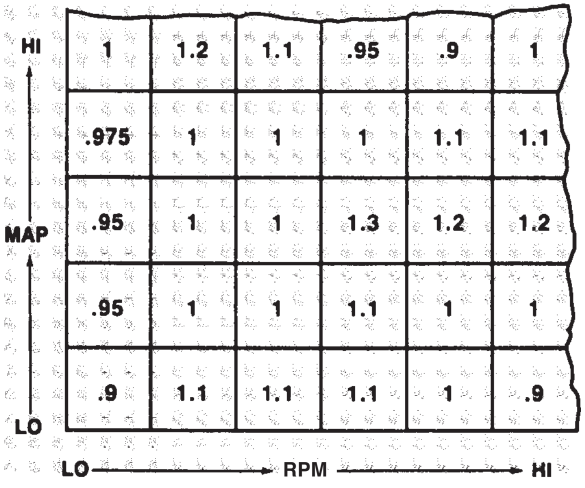
Figure 13–5 Adaptive fuel control table base values.

calculations to determine the correct pulse-width command for the injectors under the specific conditions present.

Since this table is stored in the ROM, it cannot be changed or erased. There is, however, another copy of this table in the KAM. The microprocessor uses that copy to work from, and the base values in each of the cells of the KAM copy of the table can be modified according to what the computer learns through its adaptive strategy, or learning.

If the pulse-width calculation, using the base value in a given cell, does not consistently produce the desired 14.7:1 air/fuel ratio as reflected in the oxygen sensor's return signal, the adaptive fuel control adds to or subtracts from the base value in the KAM copy of the table (Figure 13–6). If the air/fuel ratio tends to be too lean, the adaptive fuel control adds to the base value. If the air/fuel ratio tends to be too rich, the adaptive fuel control subtracts from the base value. This is Ford's version of fuel trim; it is similar to GM's Block Learn and Integrator, discussed in Chapter 11.

At idle, adaptive fuel control works the same as it does at other engine speeds. The microprocessor uses the same table for pulse-width calculations at idle, but it uses cells that are used only during idle conditions. Depending on engine application, there are either four or six cells on the MAP versus RPM table for idle pulse-width calculations. The table could look something like the one shown in Figure 13–7. The idle cells, however, are not selected by MAP and RPM; they are selected according to whether the transmission is in drive or neutral, whether the A/C is on or off, and in some cases whether the A/C control switch is on or off.


HI
MAP
LO
LO
RPM
HI

1	1.2	1.1	.95	.9	1
.975	1	1	1	1.1	1.1
.95	1	1	1.3	1.2	1.2
.95	1	1	1.1	1	1
.9	1.1	1.1	1.1	1	.9

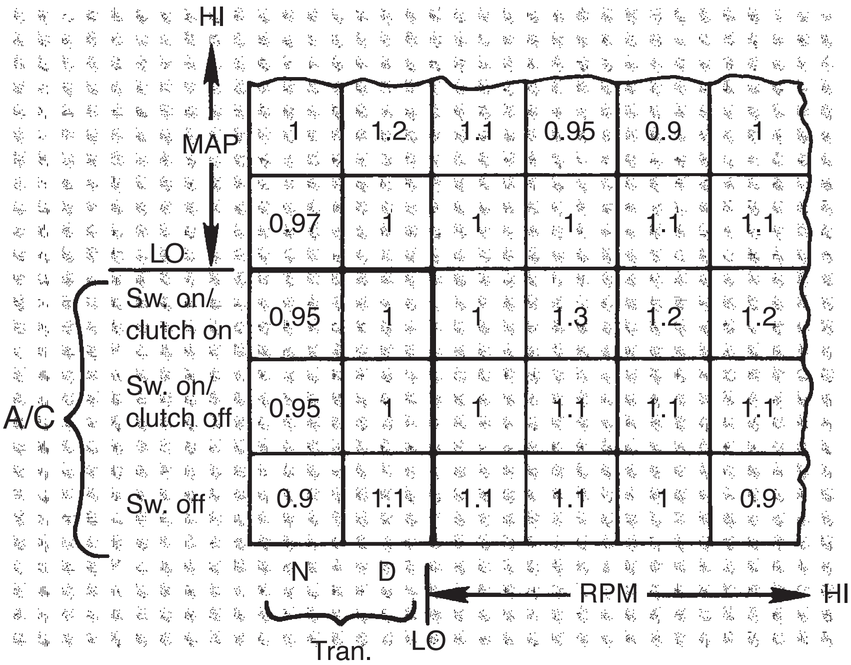
Figure 13–6 Adaptive fuel control table with adapted cell values.

Adaptive Idle Speed Strategy. The adaptive idle speed strategy is used only with CFI and EFI systems, not with carbureted engines. The idle speed strategy calculates the commands sent to the idle speed control (ISC) actuator. This device controls the amount of air admitted to the induction system bypassing the throttle valve. If the commands sent to the actuator fail to produce the calibrated idle speed, the PCM substitutes a new value in place of the one in the originally calibrated values used for the calculation. The original value is obtained from an idle table in the KAM similar to the MAP versus RPM table used for air/fuel mixture discussed previously (Figure 13–8). When idle speed is corrected, the adaptive idle speed strategy monitors the revised value needed to make the correction and records it in place of the originally recorded value in the KAM idle table.

Adaptive idle speed strategy learning occurs only under the following conditions:

- Idle speed is stabilized during base idle conditions (warm engine, automatic transmission in drive, manual transmission in neutral, and A/C off).
- System is in closed loop.
- A specific time has elapsed since idle mode began. (This time varies for different engine applications.)

Because the information learned by the adaptive strategy is stored in the KAM, it can be used or revised as needed. The learning process


HI
MAP
LO
A/C
Tran.
LO
RPM
HI

	N	D				
MAP	1	1.2	1.1	0.95	0.9	1
	0.97	1	1	1	1.1	1.1
Sw. on/ clutch on	0.95	1	1	1.3	1.2	1.2
Sw. on/ clutch off	0.95	1	1	1.1	1.1	1.1
Sw. off	0.9	1.1	1.1	1.1	1	0.9

Figure 13–7 Idle fuel control cells on MAP versus RPM table.

works constantly during stabilized, closed-loop conditions.

Other adaptive strategies incorporated into the EEC IV systems since 1985 include adaptive spark control (the computer learns to modify the range and shape of the spark advance map) and adaptive oxygen sensor aging (the computer learns how to compensate for the gradually declining signal frequency of the oxygen sensor). Their operation is similar to those just described.

Adaptive strategy also tests regularly for the possibility that corrupt data (false values) could have gotten into the KAM. If any data corruption is found, those values are erased and replaced with the original values from the ROM. Learning can then modify these values as needed.

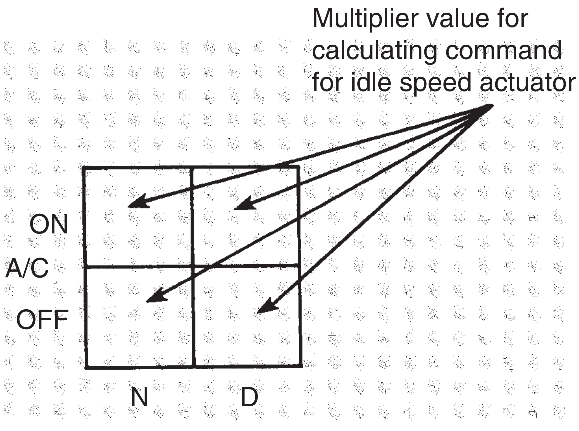

Multiplier value for calculating command for idle speed actuator
ON
A/C
OFF
N
D

Figure 13–8 Idle speed table.

Power Relay

A power relay is used to supply operational power to the PCM (Figure 13–9). The control coil of this relay is powered directly through the ignition switch. Once the ignition switch is turned on, the contact points of the relay, which are normally open, close and supply power to the PCM. The control coil of the relay is in series with a diode. If the battery's power is reversed, the diode blocks current through the relay's coil, preventing the contact points from

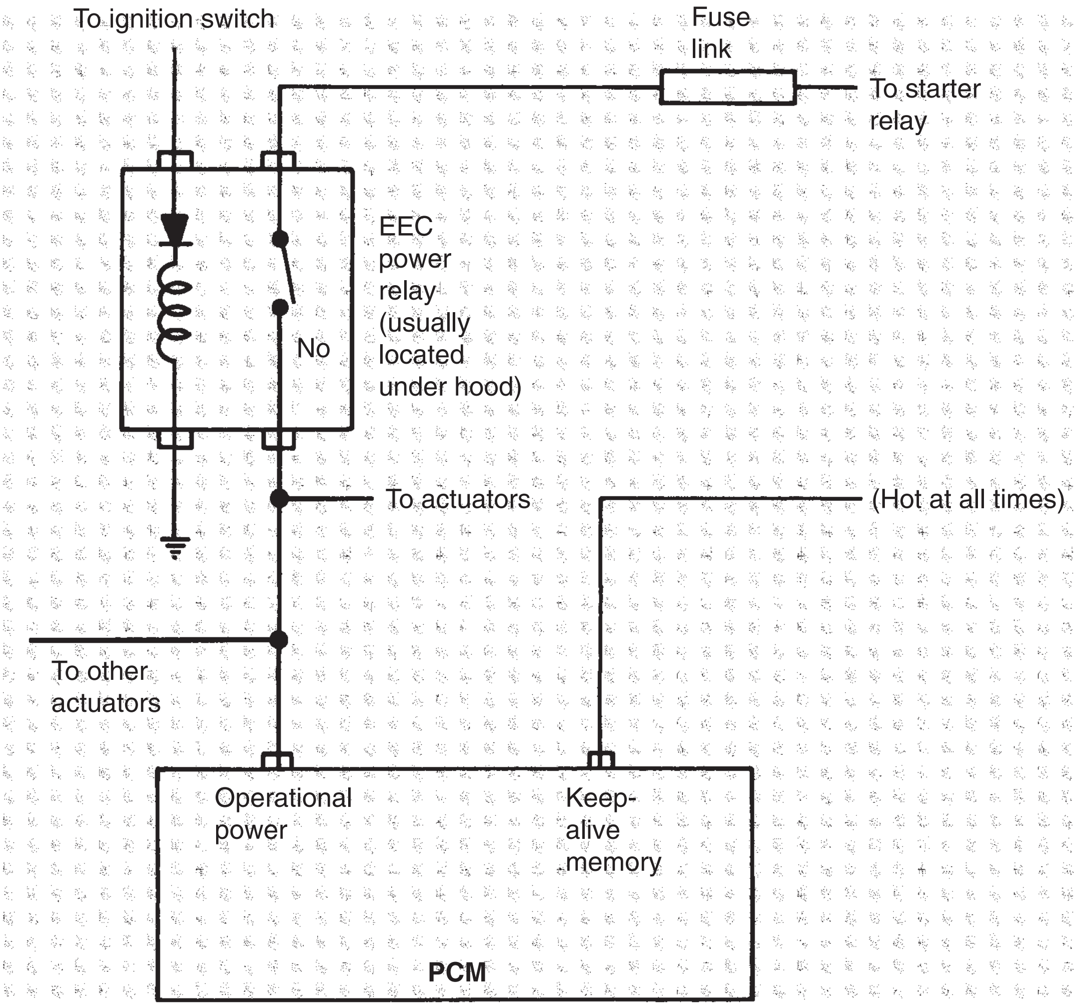


Figure 13–9 EEC power relay circuit.

closing. This protects the power circuits of the PCM from damage caused by reversed polarity.

Beginning in 1986 on some applications and becoming more widespread in 1987, the EEC power relay was integrated into a unit called the Integrated Relay Control Module (IRCM) (Figure 13–10). This unit typically contains the EEC power relay, the fuel pump relay, the low-speed Electro-Drive fan (EDF) relay (cooling fan relay), the high-speed Electro-Drive fan (HEDF) relay, and the solid-state A/C compressor clutch relay. Except for the EEC power relay, these relays are under the control of the PCM. The IRCM is located just above the radiator and cooling fan and just below the plastic support on which the emissions decal is located.

The power to the KAM does not come through the power relay but directly from a separate battery source that is always hot. If this power supply becomes disconnected, all of the learned adaptive strategy will be erased. Keeping this circuit powered requires very little current (only a few

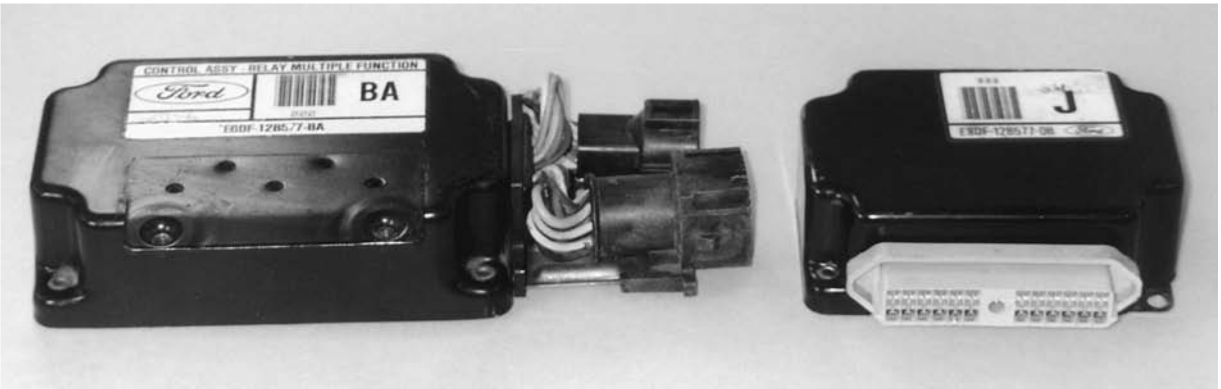


Figure 13–10 IRCMs.

milliamps) and does not discharge the battery even if the vehicle is not operated for several days. In fact, internal current in the battery will discharge it much more quickly than the minuscule KAM current draw.

Because the KAM is not protected by the power relay, its circuitry is designed to be less susceptible to reverse polarity damage. Care should always be taken to prevent such mistakes, however.

INPUTS

Engine Coolant Temperature Sensor

The engine coolant temperature (ECT) sensor is a thermistor-type sensor (Figure 13–11). Its voltage signal to the PCM normally ranges from 4.5 V when very cold to 0.3 V when the engine is hot. Its resistance values are:

- −40°F = 269 KΩ
- 32°F = 96 KΩ
- 77°F = 29 KΩ
- 248°F = 1.2 KΩ

The information it provides influences the PCM's calibration commands controlling:

- air/fuel mixture ratio
- idle speed
- EGR
- Thermactor air
- canister purge (CANP)
- choke voltage
- temperature-compensated accelerator pump
- upshift light

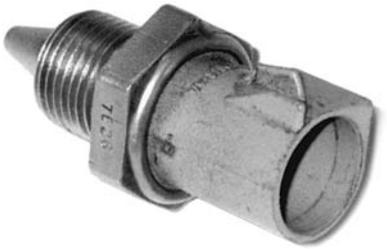


Figure 13–11 ECT sensor.

Pressure Sensors

Ford's pressure sensors operate differently than those discussed in previous chapters. They use a pressure-sensitive variable **capacitor** (Figure 13–12). The capacitor is formed by two conductive plates separated by a thin air space and a thin layer of insulating material. One plate (the positive plate) is a thin copper film on a round, rigid ceramic bed with a thin film of insulating material sprayed over the copper. The other plate (the negative plate) is also a thin copper plate on the underside of a round ceramic disk, but this disk is slightly flexible. The flexible ceramic disk

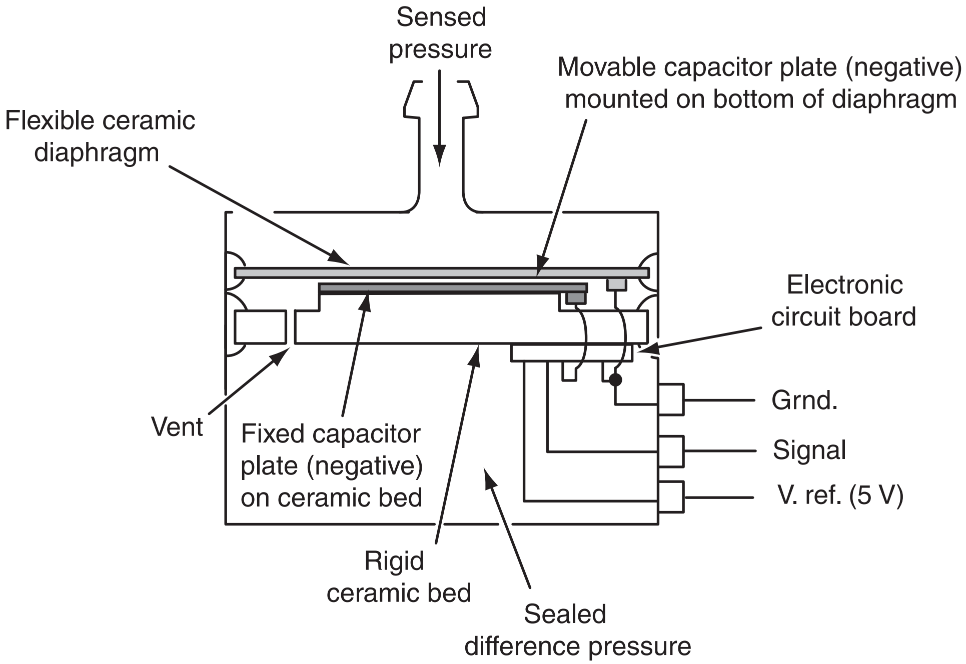

Sensed pressure
Movable capacitor plate (negative) mounted on bottom of diaphragm
Flexible ceramic diaphragm
Electronic circuit board
Grnd.
Signal
V. ref. (5 V)
Vent
Fixed capacitor plate (negative) on ceramic bed
Rigid ceramic bed
Sealed difference pressure

Figure 13–12 Typical variable capacitor pressure sensor.

is mounted on top of the rigid ceramic bed with a thin adhesive strip around the entire circumference. The adhesive strip makes an airtight seal, spacing the two copper plates a few thousandths of an inch apart.

This assembly makes up the ceramic body of the sensor; it is mounted in a plastic housing. The area below the ceramic body is sealed from the area above it. A small hole through the ceramic bed vents the area between the copper plates to the sealed, reference pressure below the ceramic bed. The space above the ceramic body is exposed to the monitored pressure.

Electronic circuitry and components are attached to the bottom of the rigid ceramic bed. Each capacitor plate has a wire that connects it to the electronic circuitry. Additional wires connect the circuitry and the negative plate to the PCM.

If the pressure sensed is lower than the reference pressure between the plates, the diaphragm flexes outward, moving the plates farther apart. This *lowers* the capacitance of the capacitor. As the sensed pressure increases, the diaphragm is forced inward, moving the plates closer together. This *increases* the capacitance of the sensor. The electronic circuit, powered by the reference voltage (VREF) from the PCM, measures the capacitance of the variable capacitor and sends a corresponding electrical signal back to the PCM.

Manifold Absolute Pressure Sensor

In addition to being a variable capacitor, the MAP sensor used on EEC IV systems is a frequency-generating device (Figure 13–13). An additional chip in the sensor's electronic circuit produces a frequency signal corresponding to the capacitance. The capacitance, as we have seen, is a function of the relative distance of the plates and thus of manifold pressure. This frequency signal is sent to the PCM.

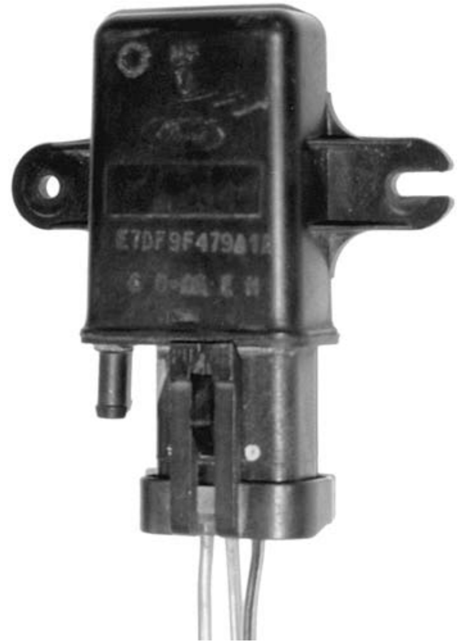


Figure 13–13 MAP sensor.

The frequency signal this sensor delivers to the PCM is actually a square wave that oscillates between 0 and 5 V at the defined frequency. Therefore, this MAP sensor is sometimes referred to as a digital MAP sensor. The signal is turned on the same amount of time that it is turned off, regardless of its frequency, resulting in a 50 percent on-time. That is, regardless of whether it is cycling at a frequency of 100 Hz (typical no-load idle) or 159 Hz (typical barometric pressure [BP] or WOT operation at sea level), the voltage will be at 5 V for 0.5 second of every second and at 0 V for 0.5 second of every second. The measured frequency indicates how many full on and off cycles of the voltage occur in the time frame of 1 second.

Ultimately, much as an analog MAP sensor delivers a high voltage to the PCM when the sensed pressure is high and a low voltage when the sensed pressure is low, this digital MAP sensor delivers a high-frequency signal to the PCM when the sensed pressure is high and a low-frequency signal when the sensed pressure is low.

If you apply a voltmeter directly to the sensor's output circuit, you will see a steady voltage signal of about 2.5 V. This will change very little regardless of manifold pressure because it is not the voltage of the output that conveys the information. Actually, the signal does change (more or fewer pulses per second) in response to changes in manifold pressure, but the frequency is much more rapid than even the fastest voltmeter can display. The meter effectively gives just an average voltage reading, which is not what the computer is looking at.

During the lowest manifold pressure conditions (highest vacuum, lowest load, as during deceleration), the sensor's signal frequency is about 92 cycles per second (92 Hz). At WOT, the manifold pressure is nearly equal to atmospheric pressure. At sea level the frequency is about 159 Hz. The PCM reads the frequency as a manifold pressure value. The MAP sensor's input affects:

- air/fuel ratio
- EGR flow
- ignition timing

Those EEC IV engine applications using a manifold pressure sensor do not use a separate barometric pressure (BP) sensor. Instead, the PCM uses a different strategy, using the MAP sensor to measure barometric pressure during two specific conditions. During the brief period of time between when the ignition is turned on and the starter begins to crank, the PCM takes a reading from the MAP sensor. The pressure in the intake manifold is atmospheric pressure during this period. The PCM stores this MAP reading in its RAM memory as a BP reading. In addition, during WOT operation, manifold pressure is almost the same as atmospheric pressure. While there is a slight difference because of intake system aerodynamic friction, this difference is predictable for any specific engine. Thus, during WOT, the PCM will adjust the MAP reading for the difference between manifold pressure and atmospheric pressure. This reading will then be used to update the BP reading stored in RAM. Obviously, this will be very close to the start-up reading unless the vehicle has changed altitude without achieving WOT, or driven so long the weather has changed substantially.

Also worth mentioning is the fact that the MAP sensor was mounted in the fender well area or fairly low on the firewall through 1986. Because fuel vapors could react with the protective gel within the sensor itself, causing it to loosen, the gel would eventually make its way into the vacuum hose and plug it, resulting in overly rich air/fuel mixtures. Beginning in the 1987 model year, the location was changed to the top of the firewall area as part of the effort to keep fuel out of the sensor.

Barometric Pressure Sensor

As stated previously, engine applications that utilize a MAP sensor do not use a full-time BP sensor but, instead, use the MAP sensor to update the BP values during engine start or WOT operation. However, engines with a vane air flow (VAF) meter must utilize a full-time BP sensor because, while the VAF meter measures engine load by measuring the volume of intake air, it cannot measure the density of the air as affected by barometric pressure. Additionally, beginning with the 1989 model year when Ford introduced the mass air flow (MAF) sensor and through the 1991 model year, a full-time BP sensor was used with the MAF sensor on some applications, even though a MAF sensor can compensate for barometric pressure values. For example, full-time BP sensors were used with MAF sensors on automatic transmission versions of the 4.0-L V6 through 1991, but the manual transmission version used the MAF sensor alone. By the 1992 model year, the BP sensors were eliminated on MAF sensor applications.

In those applications that used a full-time BP sensor, the sensor itself was essentially a MAP sensor in its design, except that a loose fitting collar was placed around the atmospheric vent (Figure 13–14). Because it looks exactly like the MAP sensor used on other applications and because the PCM recognizes the resulting signal as representing full-time BP values, the collar was present to keep someone from inadvertently mistaking this full-time BP sensor for a MAP sensor and fitting a vacuum hose to the vent. The BP sensor's input affects:

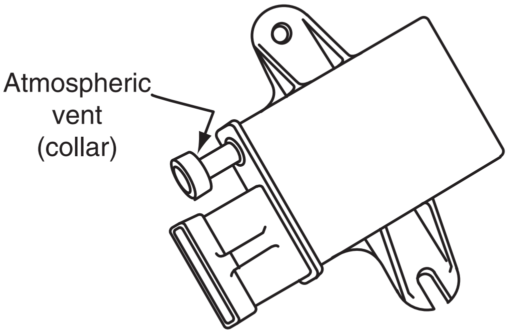


Figure 13–14 BP sensor.

- air/fuel ratio
- EGR flow

Throttle Position Sensor

The throttle position sensor (TPS) is a variable potentiometer monitoring the position and movement of the throttle butterfly plate. It provides

Diagnostic & Service Tip

Many of the connectors used on Ford systems have locking tabs that may be inadvertently broken by technicians who try to pull outward on them to release them. These locking tabs are stamped with the word "PUSH" and should be pushed toward the body of the component for a quick, easy release of the connector. The components that typically have this style of connector include the MAP and BP sensors, TFI ignition modules, EEC power relays, and fuel pump relays.

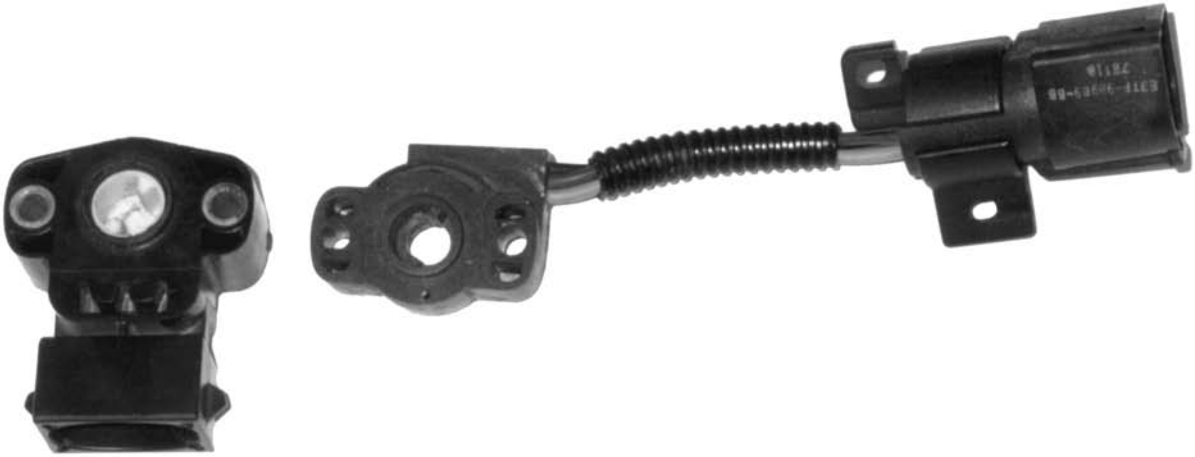


Figure 13–15 Throttle position sensors.

a reduced return voltage signal to the PCM indicating the throttle position and tracing its recent movement.

Known originally by Ford technicians as the TP sensor, the TPS used on fuel-injected Ford engines (Figure 13–15) is a rotary type that is mounted on the end of the throttle shaft and at the side of the throttle body. The potentiometer's resistor forms an arc around the axis of the throttle shaft. The potentiometer's wiper pivots from the center and directly imitates the rotation of the throttle shaft. The throttle shaft engages and drives the potentiometer's wiper. The PCM applies a 5-V reference voltage to one end of the potentiometer's resistor and a ground to the other end. The TPS returns a value to the PCM on the signal wire of about 1 V (±0.2 V) at closed throttle (idle) and approximately 4 to 4.5 V at WOT. Some throttle position sensors are adjustable so as to correct the voltage at closed throttle (idle); some are not. The PCM uses the TPS primarily to identify "driver demand" by identifying the position of the throttle but also uses it to identify how quickly the throttle is moved.

Diagnostic & Service Tip

The most frequent problem by far with throttle position sensors is a worn spot on the variable resistor, causing a high- or low-voltage spike in the return signal. Although this spike can be observed on a sensitive voltmeter, the use of a lab scope provides the easiest method to identify this problem due to its ability to draw a trace of the signal; any voltage spike will be immediately visible.

The next most frequent problem with throttle position sensors is loss of resistance-free connection through the ground circuit. This will not let the information signal get reduced to the proper voltage, either leaving it at full reference voltage (causing starting problems because the computer assumes the throttle is wide open and initiates clear flood mode) or simply raising the output signal corresponding to the voltage drop through the high resistance connection. The latter situation throws off the signal consistently on the lower range and makes it completely inaccurate in the upper range.

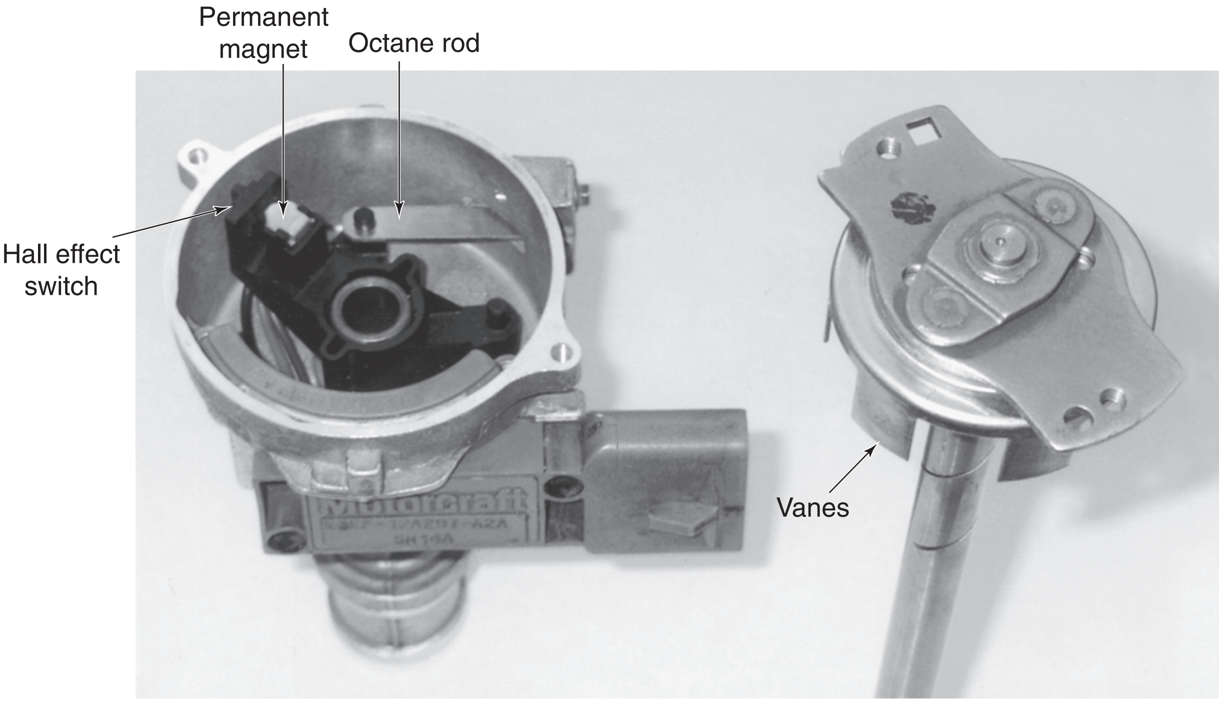


Figure 13–16 A TFI-IV distributor.

Profile Ignition Pickup (PIP) Sensor

A Hall effect switch generates the tach reference signal, known as the Profile Ignition Pickup **(PIP) signal.** This switch is therefore called the PIP sensor; it provides the PCM information about engine speed and crankshaft position (CKP). On engines with a distributor, the PIP sensor is in the distributor (Figure 13–16).

In 1986, Ford introduced sequential electronic fuel injection (SEFI) on the 5.0-L engine in passenger cars. In a sequential fuel injection system, the computer pulses each injector individually in the firing order. To do so, the computer must know where the engine is in its cycle, so it can pulse, for example, the number 3 injector during the intake stroke for cylinder number 3. So that the PCM can identify the engine's place in the cycle, Ford engineers made one of the PIP sensor trigger vanes narrower than the others. As the narrow vane passes between the magnet and the crystal, a shorter on-time occurs in that part of the signal (Figure 13–17). This shorter pulse is called the *Signature PIP.* The PCM recognizes the Signature PIP as the second cylinder in the firing order. Being able to recognize any given cylinder in the firing order, combined with a hardwired memory of the firing sequence and having a PIP signal counting program, enables the PCM to pulse each fuel injector in the proper sequence. In reality, even the non-sequential version of Ford's EFI system uses Signature PIP due to the bank-to-bank firing strategy (described later in this chapter) that the PCM uses to pulse the fuel injectors. The narrow vane enables the PCM to know which group of fuel injectors is to be pulsed next.

In 1989, Ford introduced their Distributorless Ignition System (DIS) on applications such as the

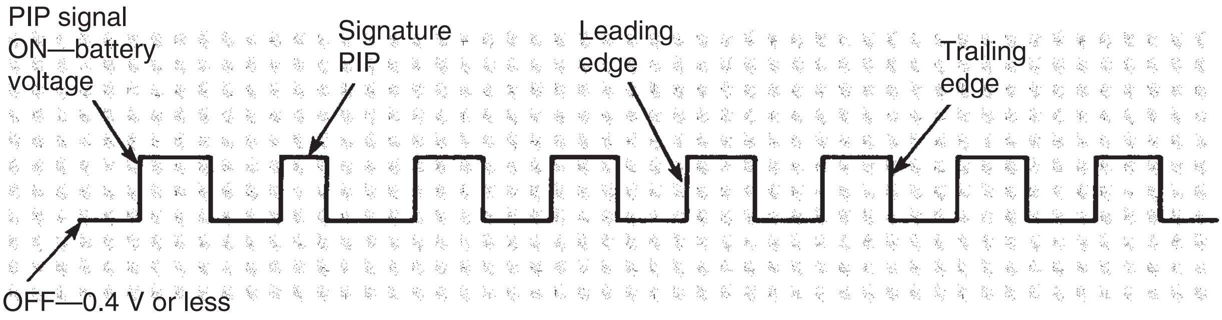


Figure 13–17 PIP signal for 5.0-L sequential fuel injection engine.

3.8-L supercharged engine, the 3.0-L special high-output (SHO) engine, and the 2.3-L engine used in the Ranger pickup truck (Figure 13–18). On these applications, the PIP sensor is located on the front of the engine, just behind the crankshaft pulley and hub assembly (Figure 13–19). A vane cup on the back of the pulley triggers the Hall effect PIP sensor switch (Figure 13–20). Since the switch is mounted on the crankshaft where it monitors two crankshaft revolutions per engine cycle, only one vane is needed for each pair of companion cylinders. As the leading edge of the vane moves between the Hall effect switch magnet and the crystal, the PIP signal rises quickly to battery voltage (Figure 13–21). The vanes on most engines are configured so a PIP signal goes to battery voltage each time a piston reaches 10 degrees BTDC. As the trailing edge of the

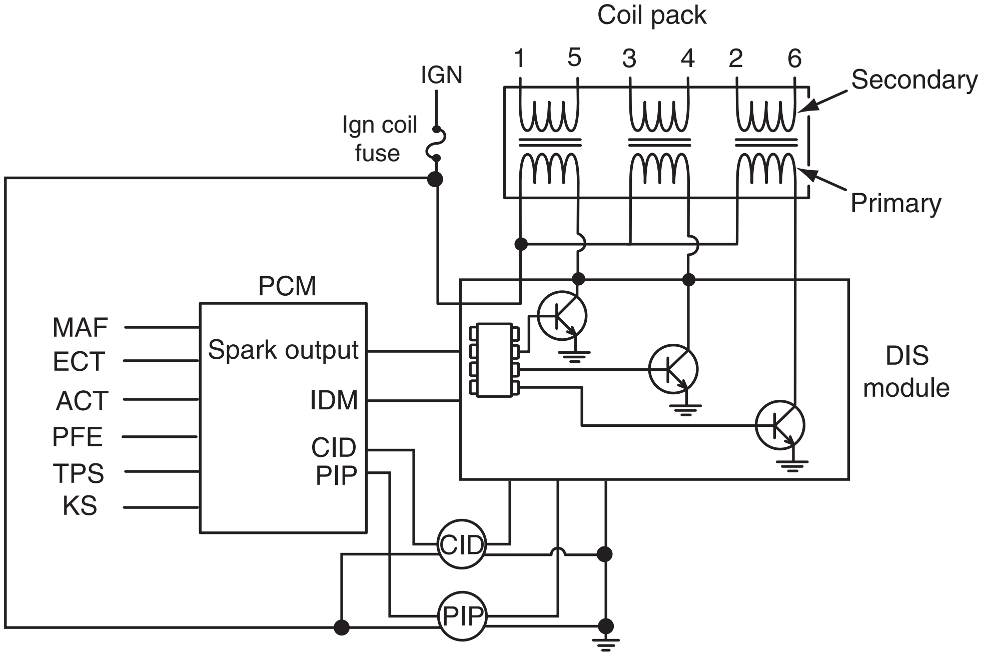


Figure 13–18 DIS, supercharged 3.8-L engine.

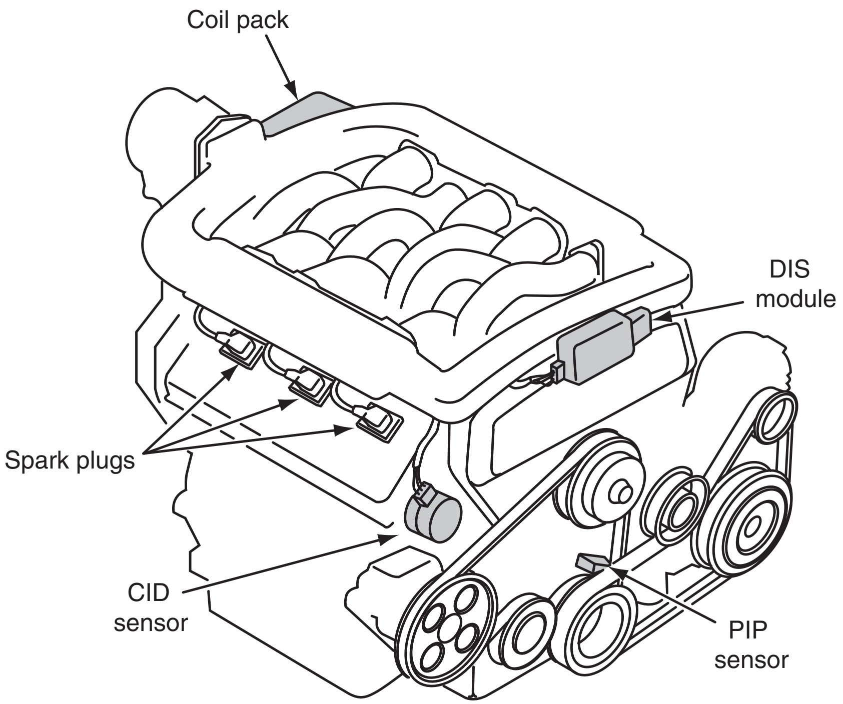


Figure 13–19 DIS components, 3.0-L SHO engine.

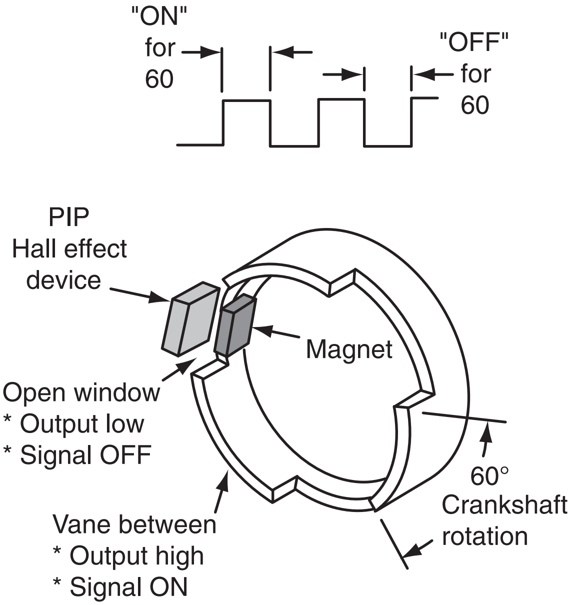


Figure 13–20 PIP sensor, supercharged 3.8-L and 3.0-L SHO engines.

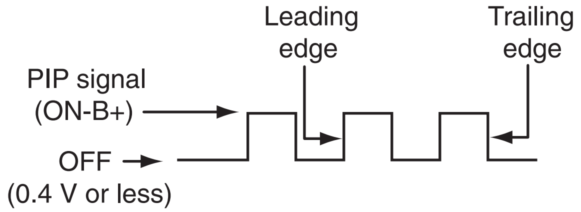


Figure 13–21 PIP signal.

vane moves from between the magnet and the crystal, the PIP signal drops to 0.4 V or less.

Cylinder Identification (CID) Sensor

Ford's DIS was introduced in the 1989 model year. This system uses a separate ignition coil for each pair of companion cylinders. Companion cylinders are cylinders 360 degrees apart in the 720 degrees of the engine cycle. For each pair of companion cylinders, one approaches the top of its compression stroke while the other approaches the top of its exhaust stroke; the positions reverse the next time. This ignition system (one of the waste spark family of ignition systems) fires the spark plugs in each companion cylinder simultaneously, one for its combustion and power stroke, the other (the "waste" spark) at the end of its exhaust stroke. The PCM calculates the proper spark advance and instructs the DIS module when to fire the coil. But the DIS module must determine which coil to fire. To know that, it must have information about which cylinder is ready for combustion ignition.

The CID sensor is also a Hall effect switch. On the 3.0-L SHO engine, the CID sensor is mounted on the right end of the rear head; one of the overhead camshafts drives it (Figure 13–19). On the 3.8-L engine the CID sensor mounts where the distributor used to be on an earlier engine, driven directly by the camshaft. On both these engines, the camshaft drives a single vane cup (Figure 13–22). As the leading edge of the vane moves between the Hall effect switch magnet and crystal, the CID signal rises to battery voltage. This tells the DIS module and the PCM that the number 1 cylinder is at 26 degrees ATDC on its power stroke. As the trailing edge of the vane moves out from between the Hall effect switch magnet and crystal, the CID signal drops to 0.4 V or less. This in turn tells the DIS module and the PCM that the number 1 cylinder is at 26 degrees ATDC on its intake stroke. Either transition, voltage either rising or falling, identifies the position of the number 1 cylinder. The DIS module uses this information during cranking to determine which coil to fire first.

Because both of these engine types are sequentially fuel injected (the 3.8-L only after model year 1988), the PCM uses the CID signal to determine the injector pulse sequence, just as it uses the Signature PIP on sequentially fuel injected engines using a distributor.

On the DIS 2.3-L engine, the CID sensor is combined with the PIP sensor behind the crankshaft pulley and hub assembly (Figure 13–23). The 2.3-L engine's CID sensor works like those

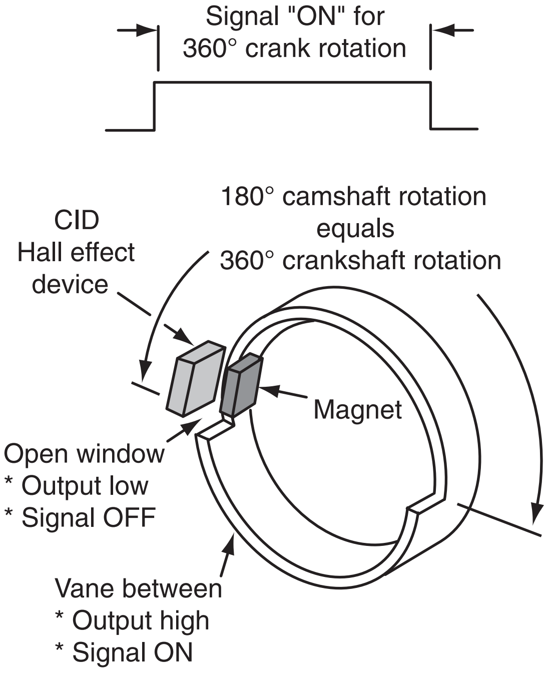


Figure 13–22 CID sensor, supercharged 3.8-L and 3.0-L SHO engines.

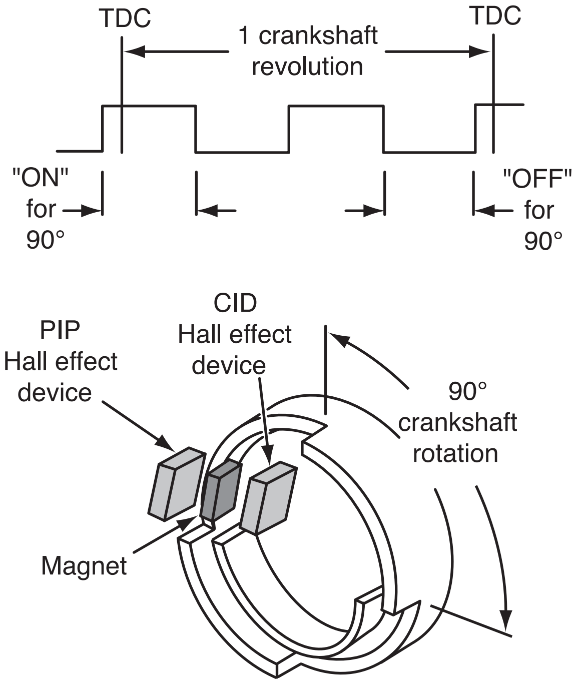


Figure 13–23 PIP sensor, 2.3-L, dual plug engine.

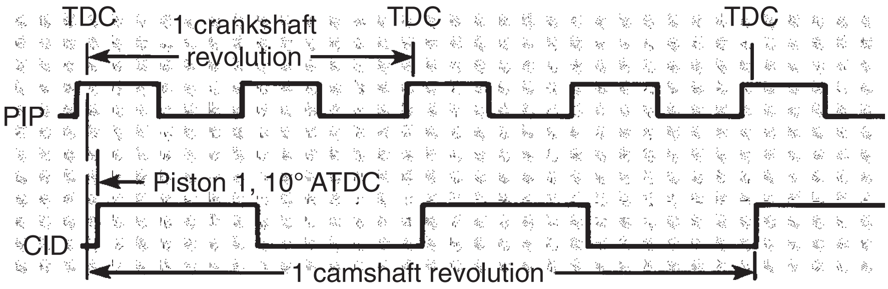


Figure 13–24 CID and PIP sensor signals.

on the 3.0- and 3.8-L engines, with one important exception. Because the single vane triggering the CID sensors is on the crankshaft pulley, it produces two high CID and two low CID signals per engine cycle (Figure 13–24). Therefore, none of the transitions in the CID signal uniquely identify the number 1 cylinder. When the signal goes to the high voltage, either the number 1 or the number 4 cylinder is at 10 degrees ATDC on its power stroke. The DIS module knows to fire coil 2 in response to the next spark timing command from the PCM. When the signal goes low, either cylinder number 3 or cylinder number 2 is at 10 degrees ATDC, and the DIS module knows to fire coil 1 in response to the next spark timing command from the PCM. The CID sensor is sometimes called a *cam sensor,* though obviously on the four-cylinder engine this is a misnomer.

Ignition Diagnostic Monitor (IDM)

The Ignition Diagnostic Monitor (IDM) signal was introduced on Ford TFI-IV ignition systems beginning in the 1988 model year. A wire is connected to the negative primary terminal of the ignition coil and then connects to the PCM via a 22-KΩ resistor (Figure 13–25). The resistor protects the PCM from the voltage spike that occurs in the primary winding when current flow is turned off. On DIS applications, the IDM signal originates in the DIS ignition module and is then routed to the PCM (Figure 13–18).

The IDM is like an echo of the PCM's spark output (**SPOUT**) command. The PCM compares the IDM signal to the SPOUT signal to check that:

- The SPOUT command was carried out.
- The calculated timing advance circuit is working properly.

If the PCM sees a fault, it stores a diagnostic trouble code (DTC) in its continuous memory.

Exhaust Gas Oxygen (EGO) Sensor

The EGO sensor looks similar to the oxygen sensing unit used on other computer-controlled engine management systems and works exactly the same way. It generates a low-voltage signal in response to the difference between exhaust residual oxygen and the oxygen in the ambient air. As the fuel injection system modifies the delivered mixture in response to the oxygen sensor's signal, the oxygen signal in turn completes the closed loop and responds to the new mixture with a corrected feedback signal. Beginning in the late 1980s, Ford began using heated oxygen sensors with either three or four wires. An EGO sensor, equipped with a heating element, was referred to as a *heated exhaust gas oxygen* (HEGO) sensor.

Intake Air Temperature (IAT) Sensor

The IAT sensor (prior to OBD II standardization, known as the *air charge temperature* or

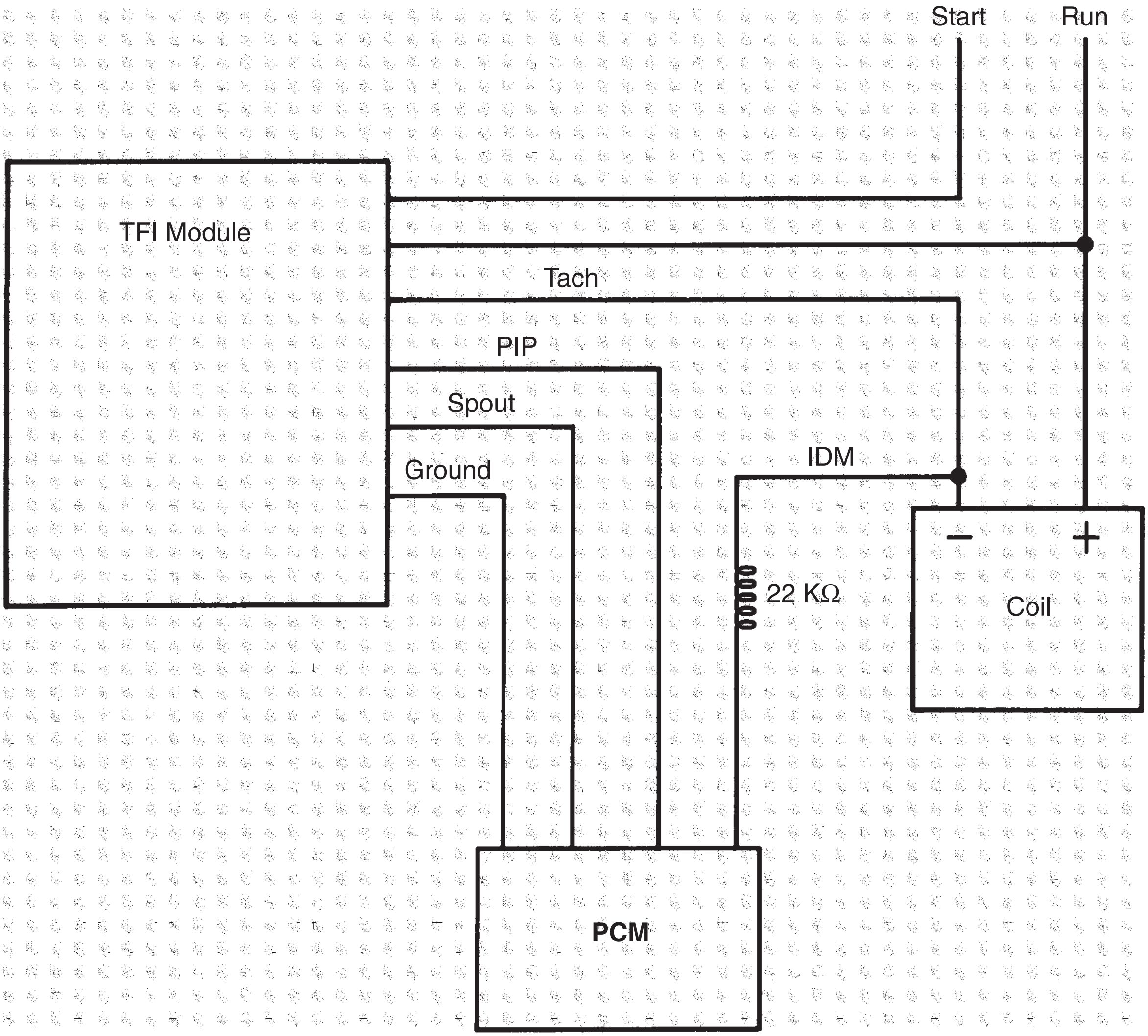


Figure 13–25 Ignition Diagnostic Monitor (IDM) circuit to PCM.

ACT sensor) measures the temperature of the air in the intake manifold that mixes with the fuel. The sensor uses a thermistor as a temperature-sensing element, just as the ECT sensor does. On the IAT sensor, however, the sensing end of the housing has openings to allow intake air to come into direct contact with the thermistor coils (Figure 13–26). The IAT sensor is screwed into the intake manifold (or into the air cleaner on 2.8-L engines). The PCM uses IAT sensor information to calculate the air/fuel mixture and spark timing advance. Voltage and resistance values for the IAT sensor are the same as those for the ECT. The IAT sensor is used on all Ford CFI and EFI applications, except when a vane meter with a vane air temperature (VAT) sensor is used (as described later in this chapter).

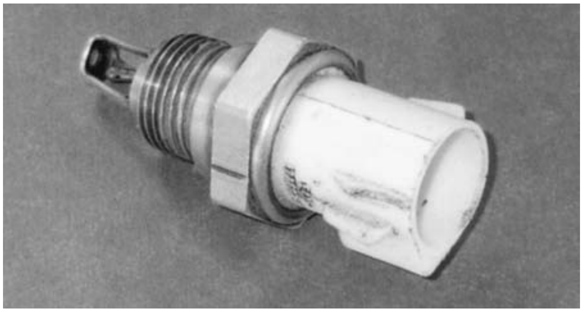


Figure 13–26 Intake air temperature (IAT) sensor.

EGR Valve Position (EVP) Sensor

The EVP sensor is a linear potentiometer mounted on top of the EGR valve. Its plunger sits on the EGR valve diaphragm and pintle assembly; it informs the PCM as to the pintle's position—closed, open, or somewhere between (Figure 13–27). The EVP sensor receives a 5-V reference voltage from the PCM and returns a voltage value that is low when the valve is closed up to a value of about 4.5 V when the valve is wide open. Two versions of this sensor are in use: a black one that carried over from EEC III and was used through 1987, and a white (light gray) one that was introduced in 1985. With the valve fully closed, the black one returns a voltage of 1 V; the acceptable range is between 0.8 V and 1.2 V. (On an EEC III application, the same EVP sensor returns a voltage of about 1.8 V with the valve closed due to the 9-V reference.) The white EVP sensor returns a voltage of about 0.4 V when the valve and sensor are new, with an acceptable range between 0.3 V and 0.7 V. Because these sensors are interchangeable physically, care must be taken to use the correct part number on a given application.

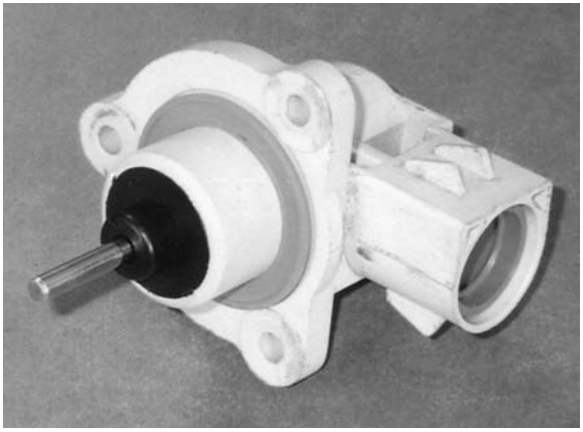


Figure 13–27 EGR valve position (EVP) sensor.

When carbon builds up within the EGR valve's pintle area, keeping the valve from fully seating, the EVP sensor returns a higher voltage to the PCM. Also, sometimes the EGR valve's metallic diaphragm will develop an indentation at the EVP sensor's contact area and therefore return a lower voltage to the PCM. Either of these conditions, when severe enough to push the voltage signal out of the proper range, can set a DTC during system diagnosis.

The PCM uses the EVP sensor's voltage signal to calculate the probable flow rate for any set of driving conditions. Unfortunately, any carbon buildup in the EGR passages can result in some inaccuracy due to the fact that this sensor measures only the EGR valve's position, not flow rate.

The EVP sensor's input is used to:

- calculate air/fuel ratio
- calculate spark advance timing
- adjust or correct EGR flow
- set a service code for an EGR valve that fails to open or close when actuated

Pressure Feedback EGR (PFE) Sensor

The PFE sensor (Figure 13–28) is a variable capacitor that works as described in the preceding section, "Pressure Sensors." It senses exhaust pressure in a chamber just under the EGR valve pintle (Figure 13–29). When the EGR valve closes, the pressure in the sensing chamber is equal to exhaust back pressure. When the EGR valve opens, pressure in this chamber is reduced because it is then exposed to intake manifold pressure, which is always lower, while the restriction at the other

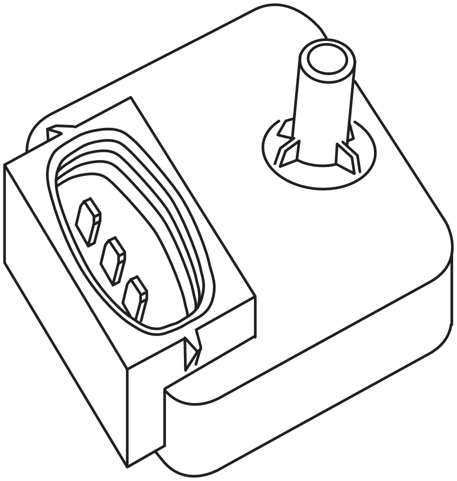


Figure 13–28 Pressure feedback EGR (PFE) sensor.

end of the chamber limits the rate at which pressure from the exhaust system can enter the chamber. The more the EGR valve opens, the more the pressure in the chamber decreases.

The PFE sensor, through its internal electronic circuitry, provides an analog voltage signal to the PCM that the PCM can compare to values on its look-up table to determine EGR flow.

The PFE sensor differs from the EVP sensor in that it monitors actual EGR flow, while the EVP sensor monitors only the EGR opening. The EVP leaves the PCM to assume there is no carbon buildup or other restriction hampering EGR flow. While this may be true for new engines, it is rarely the case for those in service for any length of time.

The PCM uses the PFE sensor information to:

- fine-tune its control of EGR valve opening
- more accurately control air/fuel ratio
- modify ignition timing

Vane Meter

The vane meter is used on some multipoint fuel injection applications, such as 1.6-L turbocharged and non-turbocharged engines, 2.3-L

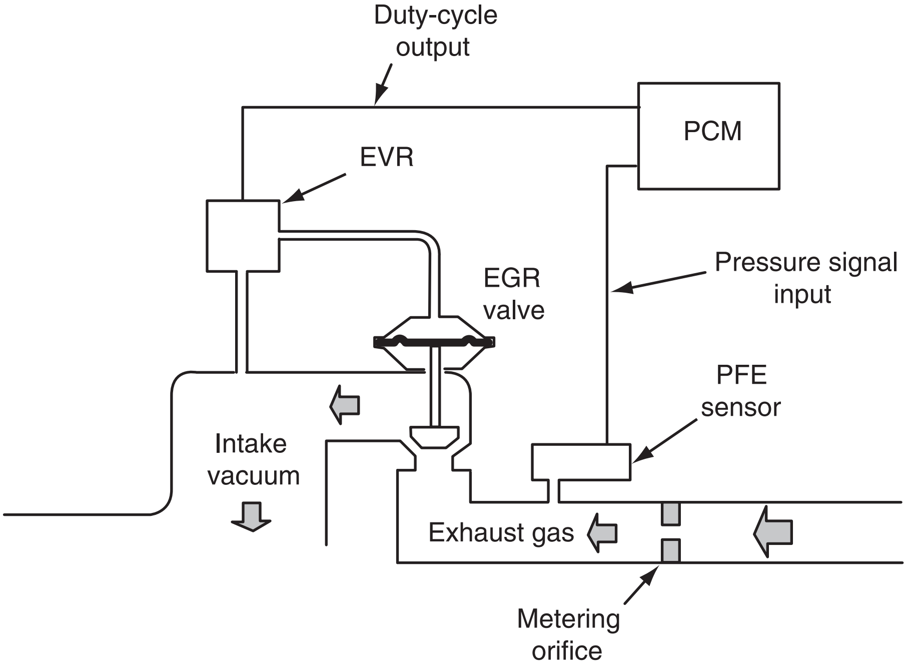


Figure 13–29 Pressure feedback EGR (PFE) sensor and EGR flow.

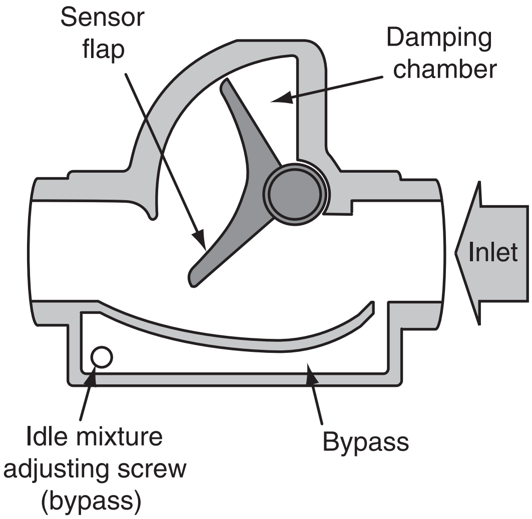


Figure 13–30 VAF sensor.

turbocharged engines, and the 2.2-L engine in the Ford Probe. It fits between the air cleaner and the throttle body; it measures the velocity of air flowing into the engine's induction system and the temperature of that air. Both of these measurements are made by sensors in the vane meter.

Vane Air Flow Sensor. The air inlet opening of the vane meter is closed by a vane, a spring-loaded door (Figure 13–30). As the throttle valve opens with the engine running, air moving into the induction system forces the vane open; the more air flow, the wider the vane opens. The vane hinges on a pivot pin. As the vane opens, it moves the wiper of a variable potentiometer, which functions as an air flow sensor for the PCM. The greater the air flow is, the higher the vane air flow (VAF) sensor's signal voltage becomes.

As the vane opens, its compensator flap pushes into a specially designed cavity below the airflow passage. There is a lull or pulse between intake strokes, particularly on four-cylinder engines, and the vane has a tendency to dip closed slightly during those periods. The sealed space behind the compensator flap acts as a damper to reduce vane flutter.

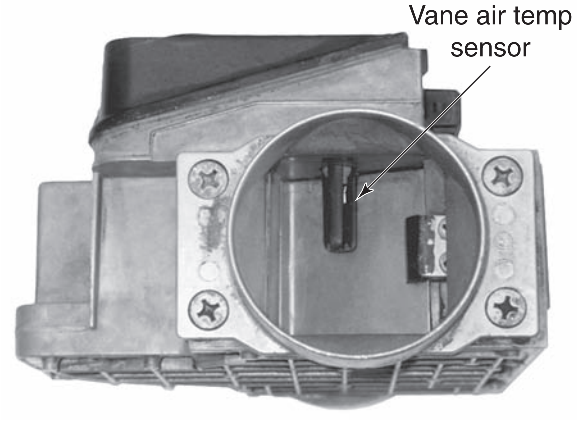


Figure 13–31 VAF meter with VAT sensor.

Vane Air Temperature Sensor. This sensor is effectively the same as the IAT sensor used on some other engine applications, except that it is located in the vane meter's air inlet opening (Figure 13–31).

Speed Density Formula. The PCM compares inputs from the VAF, VAT, and BP sensors (or the MAP sensor, depending on the engine application and the kind of sensors employed), along with those from the TPS and EVP sensors to its hardwired look-up charts. With this information it can calculate the engine's air intake volume and flow rate. This information, along with estimates of the engine's volumetric efficiency at different engine speeds and loads, is what the PCM uses to calculate exactly how much fuel should be injected. This is the Ford application of the speed density formula (see "Speed Density Formula" in Chapter 3).

Mass Air Flow Sensor. Beginning with 1989 model-year vehicles, some Ford engines used a mass air flow (MAF) sensor, replacing the MAP sensor or VAF sensor used with speed density systems. (Figures 3–15 and 3–16 in Chapter 3 illustrate a Ford MAF sensor.) The Ford unit was built by Hitachi of Japan. It is different from the Hitachi unit used by General Motors. The Ford MAF sensor is in the air tube between the air cleaner and the throttle body. A small air sample tube in the top of the MAF sensor air

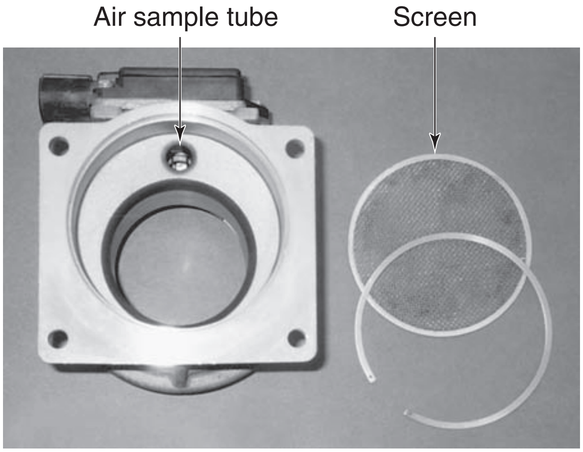


Figure 13–32 MAF sensor with air sample tube.

passage directs air across a hot wire and a cold wire (Figure 13–32). The cold wire includes a thermistor used to measure the temperature of the incoming air. The hot wire, coated with a super-thin layer of glass, wraps around a ceramic element. A module mounted on the MAF sensor body keeps it 392°F (200°C) above the ambient air temperature.

Current flow through the sensor varies from 0.5 to 1.5 amps, depending on the air's MAF rate. Voltage varies from 0.5 V at 0.225 kg (0.5 lb) of air per minute to 4.75 V at 14.16 kg (31.23 lb) of air per minute. The MAF sensor's input to the PCM affects calculations for:

- air/fuel mixture
- ignition spark timing

Idle Tracking Switch (ITS)

In the body of the idle speed control (ISC) motor assembly (which is used on some carbureted and some CFI engines) is a normally closed switch (Figure 13–33). When the throttle closes, the throttle lever presses against a plunger extending from the nose of the assembly. The pressure forces the plunger to move back slightly into the assembly and to open the switch. When the throttle opens, the switch closes again. The PCM monitors the switch to determine when the throttle is open or closed. It uses this information to control the ISC motor, to determine both when to employ it and what to set it at.

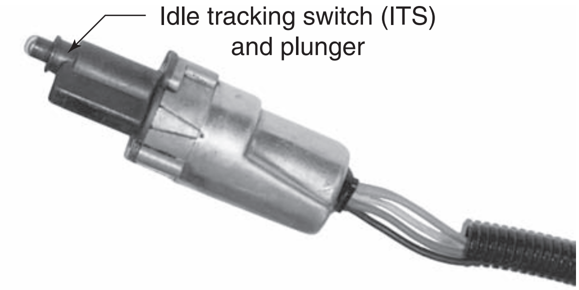


Figure 13–33 ISC motor.

Transmission Switches

The PCM must know whether the vehicle is in gear, in park, or in neutral. This information affects:

- Idle fuel and air control strategy for automatic transmission vehicles. (The torque converter loads the engine, even if the vehicle is not moving.)
- Response to rapid closing of the throttle. (If the vehicle is in gear, the PCM will issue appropriate commands for deceleration.)

For most automatic transmissions, the neutral drive switch, the same switch used to open the starter circuit when the transmission is in gear, serves as an input to the PCM (Figure 13–34). When the transmission is in neutral or park, the switch closes. A 5-V reference signal is fed through a resistor in the PCM (output pin 30), then to ground through the N/D switch. When the switch closes, voltage on the switch side of the resistor is low. By monitoring this voltage, the PCM knows whether the transmission is in gear. A diode in the switch prevents battery voltage from being applied to the PCM circuit when the starter solenoid is energized.

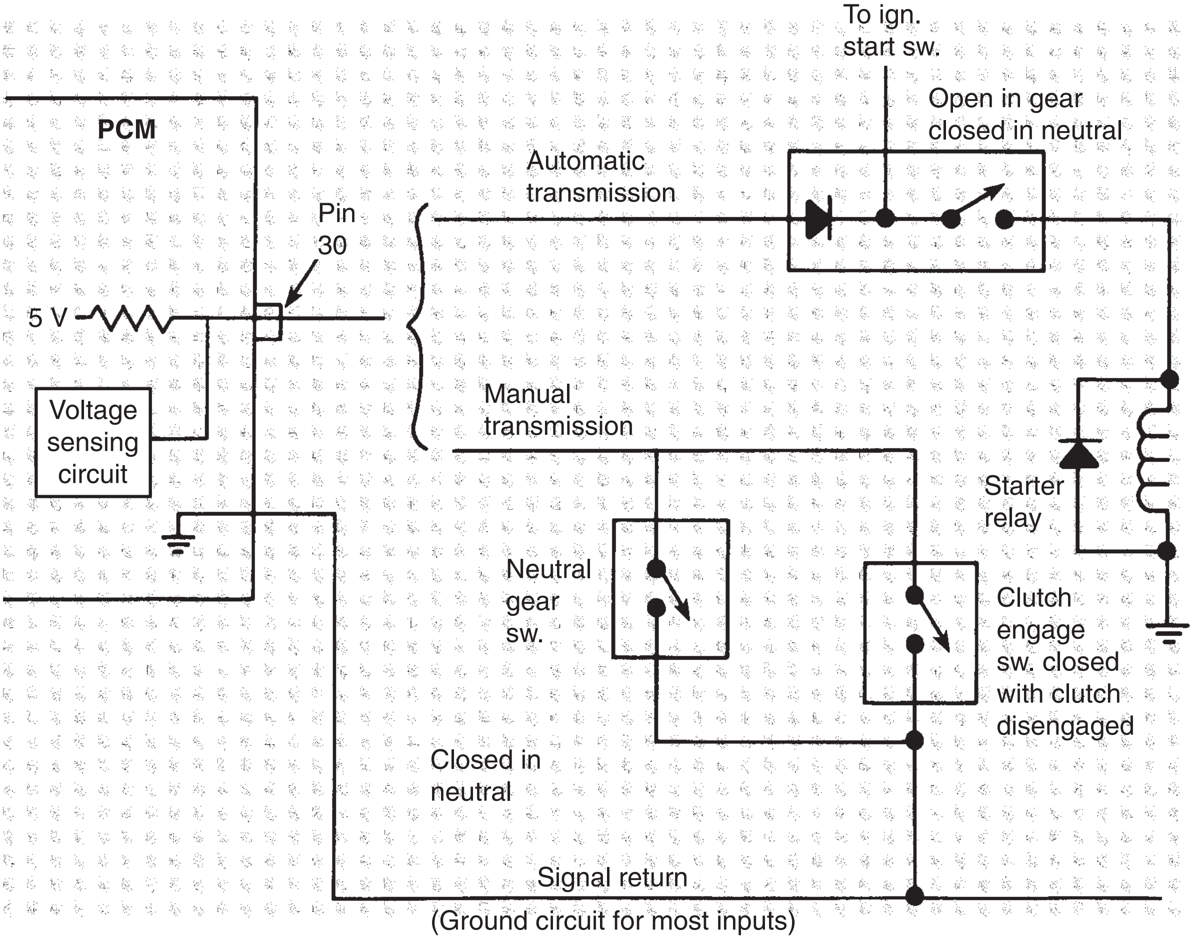


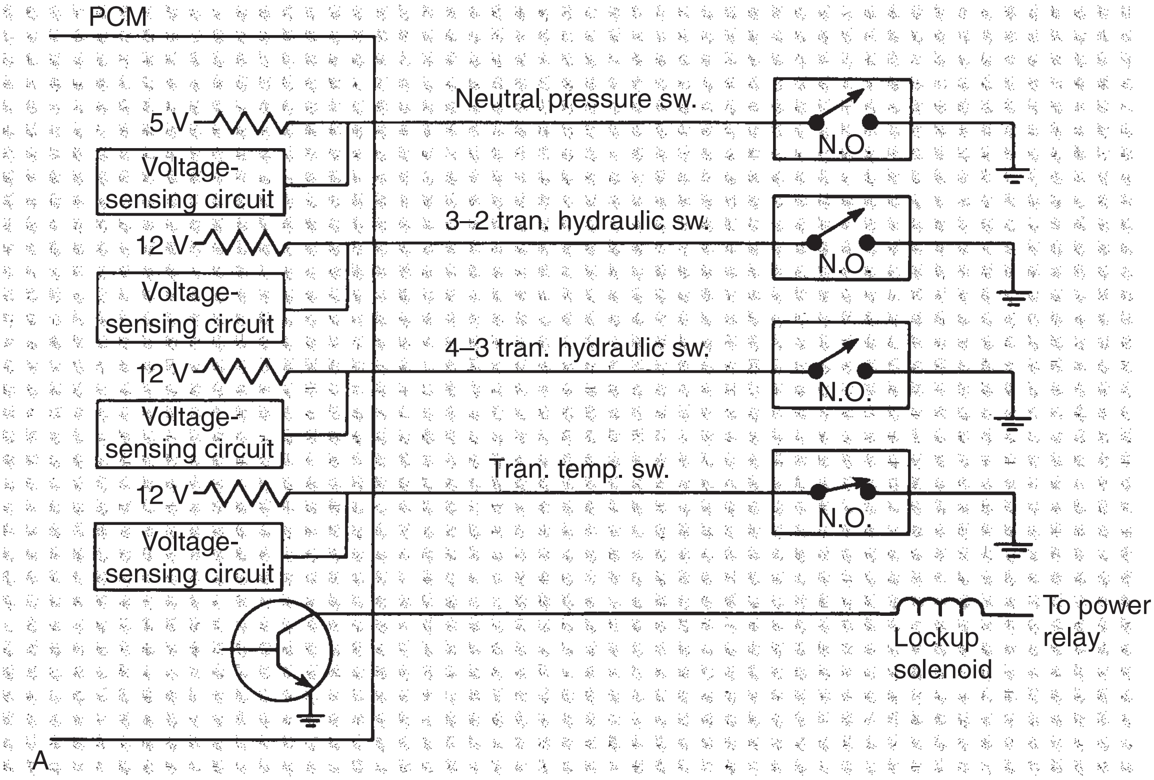
Figure 13–34 Transmission load switches.

The **AXOD (automatic transaxle overdrive)** uses three different switches to identify what gear the transmission is in. They are:

1. Neutral Pressure Switch (NPS)
2. Transmission Hydraulic Switch 3–2 (THS 3-2)
3. Transmission Hydraulic Switch 4–3 (THS 4-3)

These are normally open pressure switches screwed into the transmission valve body so they are exposed to the hydraulic pressure applied to specific bands or clutches in the transmission. When hydraulic pressure is applied, the switch closes, grounding the circuit. The PCM supplies voltage to each switch through a resistor (Figure 13–35A). By monitoring the voltage in each switch circuit, the PCM can identify each transmission gear position, with the exception that first gear cannot be distinguished from second (Figure 13–35B).

A transmission temperature switch (TTS) is employed on some AXOD transaxles to alert the PCM if the transmission fluid temperature goes too high (Figure 13–35A). The TTS is normally closed, but it opens at 275°F (135°C). It bolts directly into the valve body. If the PCM sees the



Gear position	Neutral pres. sw.	3–2 tran. hyd sw.	4–3 tran. hyd sw.
Park/neutral	Open (5 V)	Open (12 V)	Open (12 V)
First	Closed (0–1 V)	Open (12 V)	Closed (0–1 V)
Second	Closed (0–1 V)	Open (12 V)	Closed (0–1 V)
Third	Closed (0–1 V)	Closed (0–1 V)	Closed (0–1 V)
Fourth	Open (5 V)	Closed (0–1 V)	Open (12 V)
Reverse	Closed (0–1 V)	Open (12 V)	Open (12 V)

B

Figure 13–35 AXOD transmission switches.

TTS open during an operating condition in which it normally keeps the **torque converter lockup clutch** disengaged, such as a long uphill climb with a large throttle opening, it will apply the clutch to reduce the heat produced by high-torque turbulence in the torque converter.

Manual transmission applications can be taken out of gear either by the clutch or by the gearshift. Thus, the system uses two switches (Figure 13–34). A neutral gear switch (NGS) is attached to the shift linkage. It remains closed in neutral. A clutch engaged switch (CES) attaches to the clutch pedal linkage, closing when the clutch pedal is depressed (when the clutch is disengaged). Because the NGS and CES are in parallel, they must both be open for the PCM to determine that the vehicle is in gear. If either switch closes, voltage at pin 30 goes low, and the PCM knows the gear train is disengaged.

Inferred Mileage Sensor

Beginning in 1985, some light truck EEC IV vehicles came with an electronic module (inferred mileage sensor [IMS]) containing an E-cell. The IMS is energized by the power relay. After a specified amount of ignition on-time, the E-cell opens the IMS's feedback circuit to the PCM. The PCM responds by changing programmed calibrations to direct Thermactor air to the exhaust manifold for longer periods of time. It also changes the EGR flow rate. Both are measures to compensate for the "inferred" engine wear assumed to have occurred.

The IMS should not be confused with the emission maintenance warranty/extended useful life (EMW/EUL) module. There are two types of these latter units, each used on Ford trucks. The early type used an E-cell depleted after the ignition was on for a total time equivalent to about 60,000 miles. When the E-cell depleted, it triggered an indicator light on the instrument panel. This was supposed to alert the driver to replace the EGR valve and oxygen sensor. On later models, the E-cell in the module was replaced by a small microprocessor that could be reset. Replacing the EGR valve or oxygen sensor at set intervals is no longer required on other EEC IV systems applications. Replacement is required, of course, when those components fail or degrade beyond useful function.

Knock Sensor

The EEC IV engine applications using a knock sensor (KS) use a standard piezoelectric type (Figure 13–36). When excited by vibrations in frequency characteristic of detonation (knock), it sends a signal to the PCM, which can then retard spark timing advance to correct for the condition.

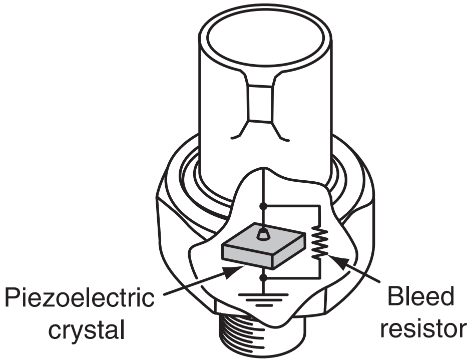


Figure 13–36 Knock sensor.

Vehicle Speed Sensor

The vehicle speed sensor (VSS), a magnetic pulse generator driven by the transmission speedometer output gear, produces eight cycles for each revolution, or 16 AC signals per revolution, or 128,000 signals per mile to the PCM. The PCM will modify this signal, convert it to a vehicle speed value, and store it in memory. In addition to vehicle speed control and depending on vehicle application, this information may be used for the control of the transmission torque converter lockup clutch, cooling fan control, and to identify deceleration conditions.

Two versions of a magnetic VSS were used. One version was used when the vehicle had onboard electronics, such as the PCM, but still retained a mechanical speedometer assembly. This VSS still allowed a speedometer cable to be attached to it (Figure 13–37). The other version had no provision for a speedometer cable to be attached (Figure 13–38); it was used on those vehicles that had an electronic speedometer and odometer assembly with either an analog or a digital display.

Brake On/Off Switch

Vehicles with the **A4LD (automatic four-speed light-duty) transmission,** such as Rangers and Broncos, use the brake on/off

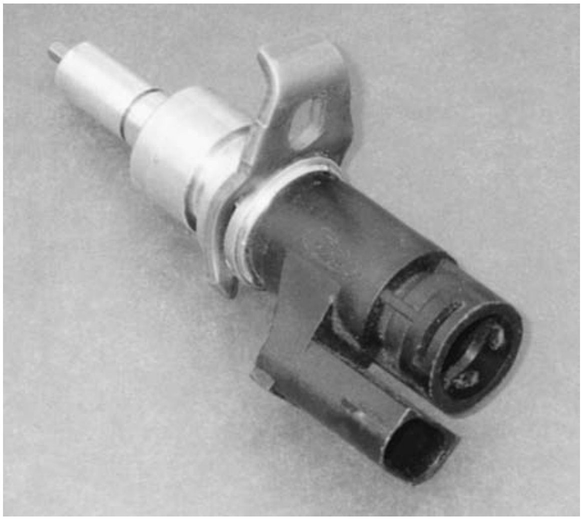


Figure 13–37 VSS used on applications that retain a speedometer cable to operate a mechanical speedometer.

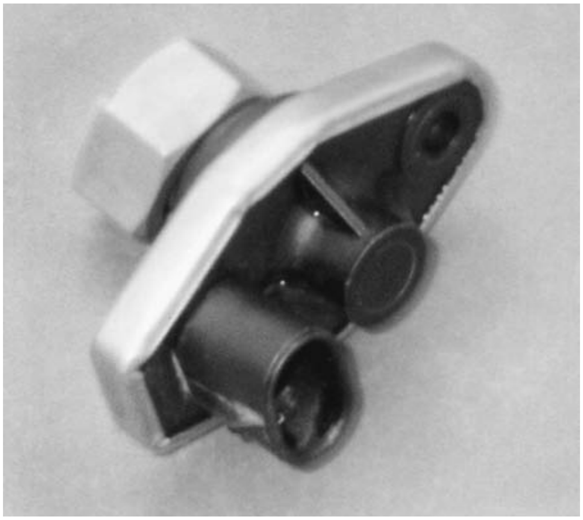


Figure 13–38 VSS used on applications that have an electronic speedometer/odometer assembly.

(BOO) switch (located in the stop lamp switch assembly) to signal the PCM when the brakes are applied. The A4LD transmission employs a PCM-controlled torque converter lockup clutch. When the switch closes, the PCM releases the lockup clutch. If the brakes are applied during idle and the transmission is in gear, the PCM may also raise idle speed to compensate for the increased engine load of the torque converter and brake booster. During a prolonged idle with the brakes applied, the PCM may also disengage the A/C compressor clutch. Use of the BOO switch has become more widespread on newer model vehicles and is used on most models today.

Power Steering Pressure Switch

The power steering pressure switch (PSPS) is located in the high-pressure side of the power steering system and is normally closed. At a pressure between 400 and 600 PSI, the switch opens. When the PCM senses that the PSPS circuit is open, it raises idle speed to compensate for the additional load caused by the hydraulic steering boost.

Air-Conditioning Demand (ACD) and Air-Conditioning Clutch Cycling Switch (ACCS)

On many applications, when the driver selects an A/C operating mode, the ACD switch (in the climate control mode switch assembly) informs the PCM that such a mode has been selected. The PCM then watches the ACCS to be able to respond with an increase in idle speed to compensate for A/C compressor load.

Ignition Switch

When the ignition switch is turned on, the EEC power relay is energized. The EEC power relay then supplies current to the PCM and to most of the actuators that the PCM controls. The PCM is then able to energize any actuator by completing its ground circuit.

OUTPUTS

Air/Fuel Mixture Control

The EEC IV system employs three different types of fuel metering devices: carburetors (referred to as feedback carburetors), throttle body injectors (referred to as Central Fuel Injection [CFI]), and port fuel injectors (referred to as Electronic Fuel Injection [EFI]). The CFI and EFI systems will be discussed here.

Central Fuel Injection. Two kinds of CFI systems are used with EEC IV applications: a high-pressure system and a low-pressure system. Each uses a throttle body unit mounted on the intake manifold in the place where a carburetor would be. Ford's CFI system equates to most other manufacturers' TBI systems.

The solenoid-operated injectors are opened by electrical command pulses from the PCM. Electrical power comes directly from the power relay, and the PCM grounds the circuit, activating the injector, for whatever pulse width (on-time) it calculates is needed for the current driving conditions. Fuel sprays from a single injector (low-pressure system, Figure 13–39) or from two injectors (high-pressure system, Figure 13–1) directly over the throttle valves. During cranking, the high-pressure CFI system pulses both injectors simultaneously in response to each PIP signal. After the engine is started, they pulse alternately at a fixed frequency. Because the fuel pressure is constant and the injector always opens the same amount (about 0.01 inch), the air/fuel mixture is controlled entirely by the injector pulse width.

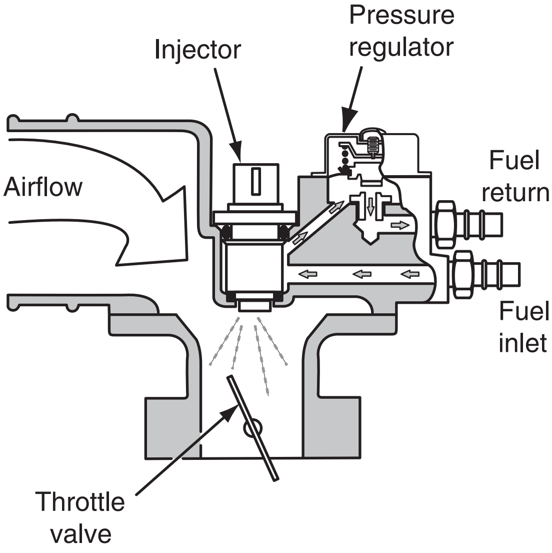


Figure 13–39 Low-pressure CFI unit.

During the mid-1980s, the 3.8-L V6 used two oxygen sensors, one on each exhaust manifold. The input from the two oxygen sensors is averaged by the PCM and then used to fine-tune the injector's pulse width.

Electronic Fuel Injection. Ford's non-sequential form of multipoint fuel injection, known as EFI, used a form of group injection known as *bank-to-bank fuel injection.* The PCM pulsed the injectors in two groups. For example, on a V8 engine, one group was comprised of the front and rear injectors at one cylinder head and the two centrally located injectors at the other cylinder head. The other bank of injectors was comprised of the other four injectors. Each group was pulsed every 720 degrees of crankshaft rotation, alternating with the other group, which was pulsed on the opposite crankshaft rotation. Each pulse delivered 100 percent of the fuel requirement for that engine cycle.

Sequential Electronic Fuel Injection. Ford introduced Sequential Electronic Fuel Injection (SEFI) on the 5.0-L V8 engine in 1986 model-year vehicles and on the 3.8-L V6 engine in 1988 model-year vehicles. By the late 1980s, most of their passenger cars had sequentially fuel-injected engines, although the light truck line was not sequentially injected until the 1990s. In the SEFI system, as with other makes, the injectors are pulsed one at a time in the engine's firing order.

Fuel Supply System

Fuel Pump. The low-pressure CFI system uses a fuel pump mounted in the fuel tank. The fuel pump relay controls it, and the pump delivers fuel to the fuel delivery assembly: the throttle body unit.

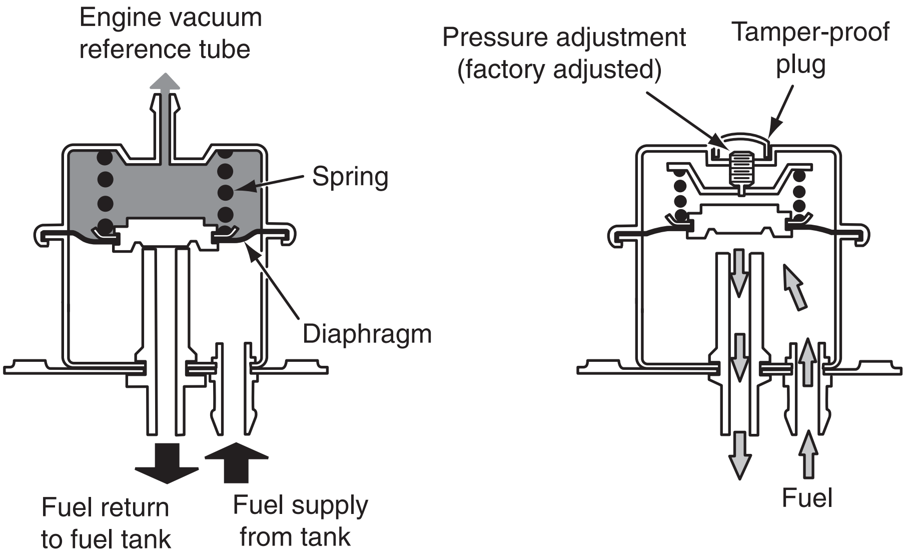
The CFI high-pressure and EFI systems use one of two fuel delivery systems. Most use a single high-pressure, in-tank electric pump that feeds fuel at about 39 PSI to the pressure regulator. Vehicles with a greater distance between the fuel tank and the engine, such as pickup trucks or vans, may use two electric fuel pumps to ensure adequate fuel pressure to the injectors without the risk of vapor lock. A low-pressure "lift pump" is mounted in the tank. It pumps fuel to an in-line high-pressure pump, which increases the pressure to about 39 PSI and sends the fuel to the pressure regulator.

Either of the high-pressure pump systems can generate an unregulated pressure of more than 100 PSI if the fuel line is blocked. If that pressure is reached, a pressure relief switch shuts off the pump.

Fuel Pressure Regulator. A pressure regulator (similar to those described in previous chapters) controls fuel pressure to the injectors (Figure 13–40). Manifold vacuum/pressure is routed to the EFI/SEFI system pressure regulator to vary the fuel rail pressure at the injectors in response to throttle position so as to compensate for changes in engine load. This delivered pressure can range from a low of about 30 PSI at high vacuum (low manifold pressure) conditions to as high as 39 PSI at WOT (high manifold pressure). On turbocharged engines, the fuel pressure at the injectors during boost conditions can allow a delivered fuel pressure as high as about 50 PSI.

The CFI systems do not employ a manifold pressure–controlled regulator; their fuel pressure stays constant. The high-pressure CFI system maintains 39 PSI (must be between 38 and 40 PSI) at the injector inlets. The low-pressure system (on the 2.3 High Swirl Combustion [HSC] engine) maintains 14.5 PSI at the injector inlet. There is no need to modulate pressure according to load with these systems because they spray fuel above the throttle plate, into air at ambient barometric pressure (BP).

Fuel Pump Relay. The fuel pump relay controls the fuel pump and is in turn controlled by the PCM (Figure 13–41). When the ignition switch is turned on, the PCM grounds the fuel pump relay coil. If the PCM does not receive a PIP signal indicating engine cranking, it will turn the fuel pump relay off after about 1 or 2 seconds. Once the engine is running, the PCM keeps the fuel pump relay energized until the ignition is turned off or until the PCM no longer receives a PIP signal.



MULTIPOINT **CFI**

Figure 13–40 Fuel pressure regulators.

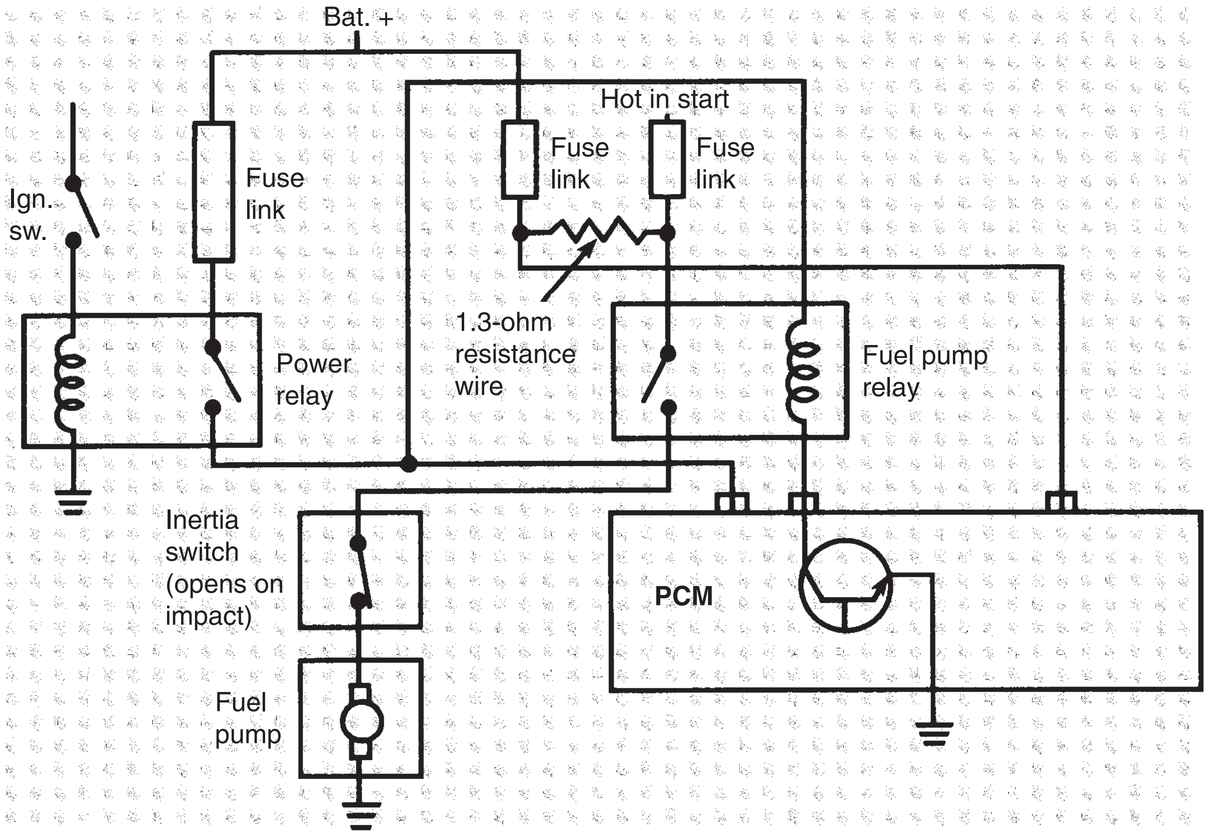


Figure 13–41 Fuel pump control circuit.

Inertia Switch. In series with the fuel pump relay is an **inertia switch** (Figure 13–42), also known as a *fuel pump cut-off switch.* Its purpose is to disable the fuel pump if the vehicle is involved in an accident to reduce the chance of a fuel fire. The inertia switch consists of a steel ball sitting in a metal cone-shaped bowl. A magnet holds the ball at the bottom of the bowl. In the event of a jolt severe enough to dislodge the ball, the ball is deflected upward by the slanted side of the bowl and strikes a lever above it. This lever triggers an over-centering spring, opening the contacts of the inertia switch and holding them open. This opens the circuit to the fuel pump and de-energizes it. It also pops up a reset button on the top of the inertia switch. Pushing the reset button back down reverses the over-center switch and closes the contacts again, enabling the fuel pump to run if the PCM energizes the fuel pump relay and sends it current.

Ford PCMs, like other manufacturers' PCMs, will de-energize the fuel pump relay if the tach reference signal to the PCM is lost, as would happen if a fuel supply line ruptured and caused engine stall. However, Ford engineers felt it necessary to use an inertia switch in addition to this safety strategy, for the following reasons:

- In case an accident were to result in a rupture of the fuel return line.
- In case an accident were to result in minor fuel leaks (in the supply line) that are not sufficient to cause engine stall.

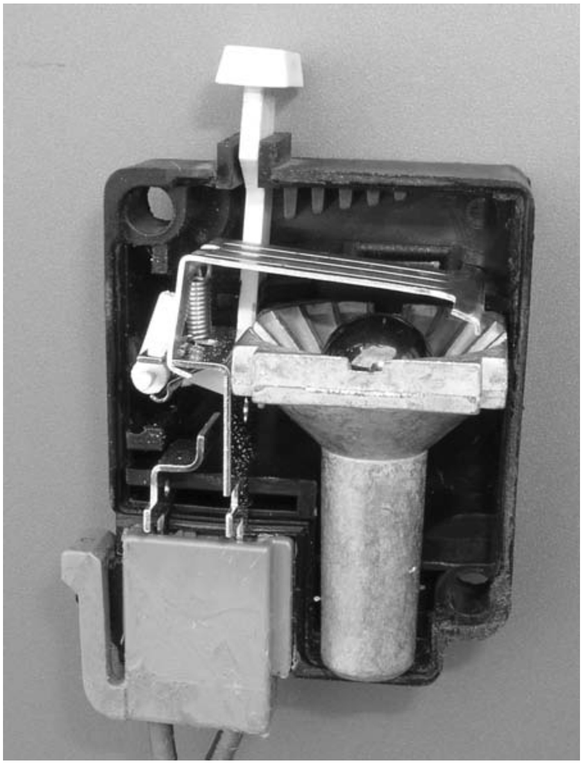


Figure 13–42 Inertia switch.

- In case an accident were to cause a rupture of the fuel supply line and also, simultaneously, short the wire between the PCM and the fuel pump relay to ground, thus keeping the fuel pump relay energized.

If the engine cranks but will not start, and the fuel pump is not heard to operate for 2 seconds after turning on the ignition switch, check to see if the inertia switch has been tripped. The inertia switch is used on all Ford Motor Company products, including Ford, Lincoln, Mercury, Jaguar, and Mazda.

CAUTION! When resetting a Ford inertia switch that has tripped, it is critically important for the technician to follow the resetting of the switch by pressurizing the fuel system and then performing a careful visual inspection of the entire fuel system to check it for leaks. Failure to do this when resetting a Ford inertia switch can leave the technician liable for damage resulting from any existing fuel leaks.

Diagnostic & Service Tips

Any time a fuel-injected Ford product has suddenly refused to start, the technician should first check the inertia switch. Sometimes these switches have even been triggered by another driver's parking by Braille, running into the vehicle with enough force to trigger the switch but not enough to cause damage. This author has also seen an inertia switch that was tripped because someone slammed the driver's door with great force, because someone slammed the rear lift gate on a station wagon/SUV with great force, and because a rear window had been broken by a blunt force. And, if a brief case is thrown on the front floor of the vehicle with enough force, an inertia switch that is mounted behind a kick panel may also be tripped.

This switch, sometimes located in the trunk, can also be damaged by moisture, so it is good practice to check to see if the contacts are still clean where the harness connects. Never run a jumper wire around an inertia switch except for an in-shop test. Under no circumstances should a vehicle be released to a motorist with the inertia switch disabled.

Thick Film Integrated IV Ignition System

The **Thick Film Integrated IV (TFI-IV)** ignition system takes its name from the TFI module bolted to the distributor housing. *Thick film* refers to the type of chip on which the module's circuit is printed. Its function is to turn the ignition coil primary circuit on and off and to control primary circuit dwell time. The Spark Output (SPOUT) command from the PCM is the module's signal to open the primary circuit and fire the spark. If the SPOUT circuit is open, the TFI module will open the primary circuit in response to the PIP signal. This, of course, results in base timing only, with much less spark advance than is called for in practically all driving conditions.

Spark Output. The PCM receives the PIP signal from the Hall effect switch in the distributor through the TFI module (Figure 13–43). From this signal the PCM determines engine RPM and crankshaft position (CKP). The PCM then modifies this signal (changes the spark advance timing) to achieve the best results considering the engine's speed, temperature, load, the atmospheric pressure, the EGR flow, and the air temperature. The time-modified signal is sent to the TFI module as the SPOUT signal or command.

The SPOUT signal is a digital (on-off or square wave) signal. The leading edge of the on portion of the signal causes the TFI-IV module to open the primary ignition circuit, allowing the

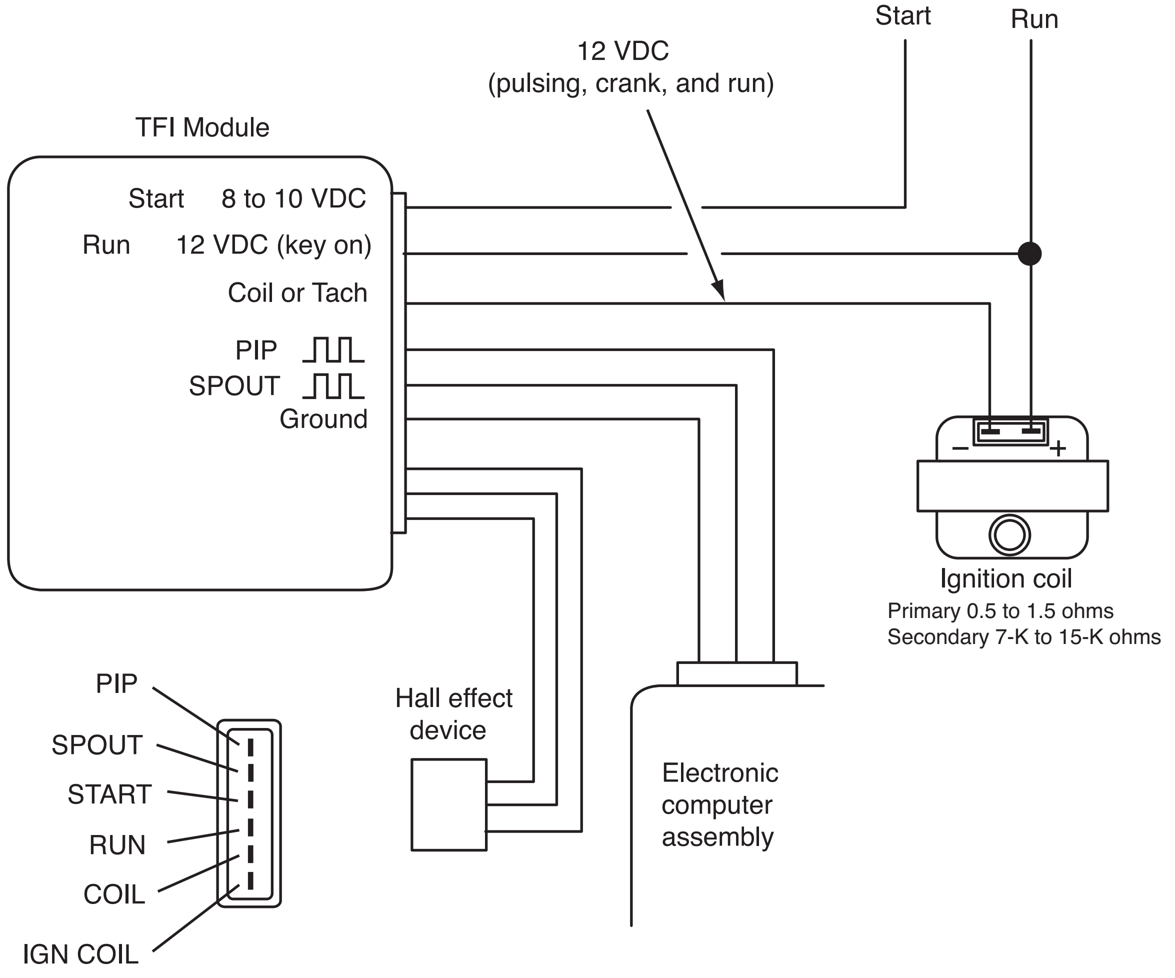


Figure 13–43 TFI-IV ignition circuit.

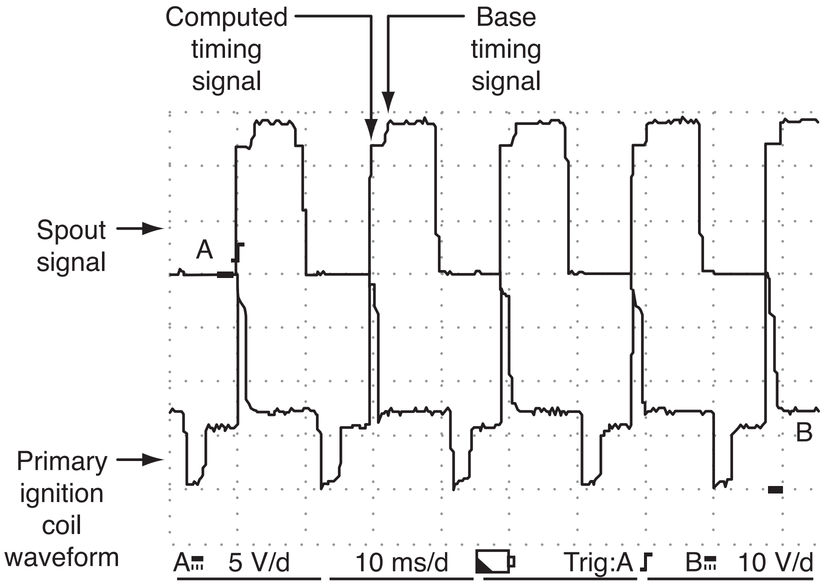


Figure 13–44 TFI-IV system waveforms with SPOUT signal on top and primary ignition coil waveform on bottom.

coil's collapsing magnetic field to generate the high voltage in the secondary windings to fire the spark plug.

If the SPOUT circuit is open, the TFI module will select the base or reference signal from the PIP signal for its spark firing timing.

Figure 13–44 shows two TFI-IV system voltage waveforms captured simultaneously on a dual trace lab scope (DSO). The SPOUT signal's voltage waveform is on top and was captured by the lab scope's Channel A lead set (Channel A = 5 V/division). The primary ignition coils' voltage waveform is displayed below the SPOUT signal and was captured by the lab scope's Channel B lead set (Channel B = 10 V/division).

As current flow is turned on in the primary ignition coil (Channel B), the voltage signal is pulled to 0 V. This is followed by a rise in the voltage to about 11 or 12 V, which represents the current-limiting ability of the TFI-IV ignition module. This keeps the primary coil winding from overheating due to over-saturation. This is followed by the voltage spike, which occurs when primary current flow is turned off (and also occurs simultaneously with the spark as it is produced in the secondary coil winding). Notice that this voltage spike occurs exactly with the major upsweep of the left edge of the SPOUT signal above it.

The SPOUT signal on Channel A is, for the most part, a digital signal that oscillates between 0 V and 14 V (charging system voltage). Each of the SPOUT signals has a notch in the upper-left corner when the SPOUT circuit's shorting bar is connected and the PCM is controlling spark timing. (Incidentally, the one signal that also has a notch in the upper-right corner represents the narrow vane of a Signature PIP distributor.) The major upsweep of the left edge of the SPOUT signal (from 0 V to about 12 V) represents the computed timing command. The final upsweep of this voltage (from 12 V to 14 V) represents the base timing signal. Therefore, the time difference between these two voltage upsweeps (the length of the short horizontal line at the 12-V value) represents how much spark advance the PCM is adding to base timing (or how many milliseconds the PCM is commanding the ignition module to fire the ignition coil ahead of the base timing signal). Notice that the ignition coil is being fired at the computed timing signal. In this screen capture, the time is adjusted to 10 ms/division. Therefore, the time difference between the computed timing command and the base timing signal is about 2 ms. If the engine were idling at 600 RPM (or 10 rotations per second, which, in turn, equates to 3600 degrees of rotation per second or 3.6 degrees of rotation per millisecond), the 2 ms of commanded spark advance would equate to about 7.2 degrees of spark advance at the crankshaft.

If a technician removes the SPOUT circuit's shorting bar, the TFI-IV system goes to base timing and the notch in the upper-left corner of the SPOUT signal disappears. The SPOUT signal's voltage upsweep from 0 V to 14 V occurs fully at the base timing signal. Simultaneously, the module begins firing the coil in line with the base timing signal. Therefore, the firing of the ignition coil is no longer being advanced 2 ms in time, as it had been when the SPOUT circuit's shorting bar was installed.

Likewise, the PIP signal (which is relayed by the ignition module to the PCM) is basically a digital 0-V/14-V signal as well. When the SPOUT circuit's shorting bar is installed, the PIP signal also has a notch in it, but in the upper-*right* corner. When the shorting bar is removed, the notch disappears. This is the ignition module's way of keeping the PCM informed as to whether the module sees continuity with the PCM on the SPOUT circuit. When continuity is present, the ignition module waits for the SPOUT command to fire the ignition coil, but when the SPOUT circuit is open, the module goes to base timing and fires the coil directly from the PIP signal.

Computer Controlled Dwell. In early TFI-IV ignition systems, dwell (the duration of the time the coil primary circuit is energized) is controlled by the TFI-IV module. In other words, the TFI-IV module decides when to turn the coil on, and as we saw with SPOUT, the PCM tells it when to turn the coil off and fire the plug. The TFI-IV module includes circuitry that monitors engine RPM and increases dwell as engine speed increases. Beginning in 1989 for a few TFI-IV applications, the PCM instead controlled the ignition dwell. The trailing edge of the SPOUT signal tells the TFI-IV module to close the primary circuit, and the leading edge tells it to open the primary circuit and fire the plug. The Computer-Controlled Dwell (CCD) system is identified by a TFI ignition module that is black in color.

The reason the system varies the dwell with engine RPM is that all that is desired from the coil is full spark for the next plug firing. It takes a certain amount of time for the coil to fully build the magnetic field, the collapse of which generates the high-voltage secondary current. To keep the coil energized longer than needed is simply to use electric power as resistance heat to make the coil hot. Dwell control began much earlier than computer controls, beginning at least with the 1976 versions of electronic ignition. Even earlier, ballast resistors were used to reduce electric current through ignition primary circuits for the same reason: to keep from overheating the coil.

E-Core Coil. The TFI-IV ignition system uses an E-core coil shaped differently from the conventional coil used on prior Ford Motor Company products. The coil core resembles two uppercase Es turned face to face. The coil windings, molded of epoxy, are wound around the Es' center horizontal bars. Because the center bars are shorter than the ones at the top and bottom, they do not quite touch each other and thus form a small air gap between them. The smaller air gap (compared to the distance between the ends of a conventional longitudinal coil core) helps the coil develop a much stronger magnetic field quickly. With no primary ballast resistor and the small core air gap, the E-coil core draws high primary circuit amperage (5.5 to 6.5 amp) and can put out as much as 50,000 V. Even though secondary circuit amperage is very small, technicians should be very careful never to allow ignition secondary voltage to shock them. On modern high-energy ignition systems, such a shock can be more than just painful.

Octane Rod Adjustment

The TFI-IV distributor has an octane rod, inserted from the outside of the distributor, used to position the Hall effect sensor (Figure 13–16). Of course, the position of the Hall effect sensor is one variable that affects base timing. Ford Motor Company has issued technical service bulletins (TSBs) on certain applications to change the octane rod for one of a different length, which will retard base timing a selected 2, 3, or 6 degrees, depending on the octane rod used. The octane rod is stamped with a number representing the amount of spark timing retard the rod will create.

Thick Film Integrated IV Ignition System: Closed Bowl. In the 1988 model year, Ford engineers introduced another version of the TFI-IV system that relocated the TFI ignition module to a remote location in a large heat sink to better allow the module to dissipate heat (Figure 13–45). The TFI module's "hole" in the side of the distributor bowl was then closed up; thus the name *closed bowl TFI-IV system.*

Electrically, in the closed bowl version of the TFI-IV system, the Hall effect sensor creates two PIP signals: PIP-A is sent directly to the PCM and PIP-B is sent directly to the TFI module. The TFI module still uses the SPOUT signal from the PCM to fire the ignition coil as in the TFI-IV universal bowl system.

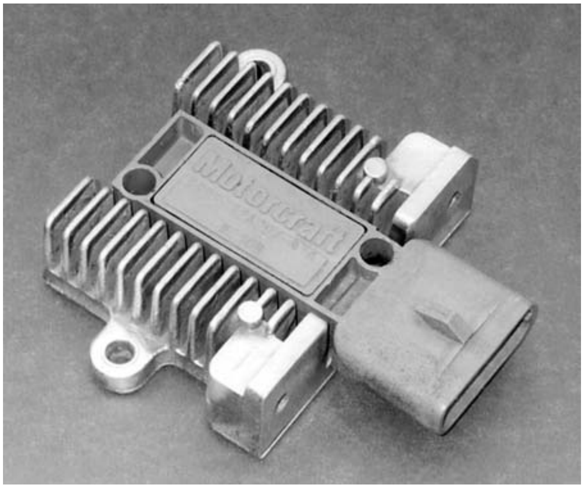


Figure 13–45 A TFI-IV ignition module mounted remotely in a heat sink, rather than on the distributor housing.

Diagnostic & Service Tip

When a TSB was issued to instruct the technician to replace the octane rod with a retard rod, some technicians have taken a short cut and simply retarded base timing by turning the distributor housing, ignoring the instruction to replace the octane rod with the retard rod provided. During normal base timing readjustments, when the distributor housing is turned to retard base timing in the primary circuit, the rotor-to-distributor cap relationship is automatically changed to compensate for the change in spark timing. When the engineers issue a TSB to replace the octane rod as a method of changing base timing without rotating the distributor housing (that is, change the primary circuit element without changing the secondary circuit element to compensate), this has the effect of correcting the rotor-to-distributor cap relationship. Ultimately, a technician should evaluate underlying concepts very carefully before deciding to shortcut any instructions provided by the manufacturer.

Distributorless Ignition System

In the 3.0-L SHO and supercharged 3.8-L engines, the PCM controls both dwell and timing. When the starter turns the engine, PIP and CID signals are fed to the Distributorless Ignition System (DIS) module and to the PCM. Once the DIS module receives a CID signal, it turns on coil 2 by providing a ground for the coil's primary circuit (Figure 13–18) in response to the next SPOUT trailing edge that it sees (Figure 13–46). Coil 2

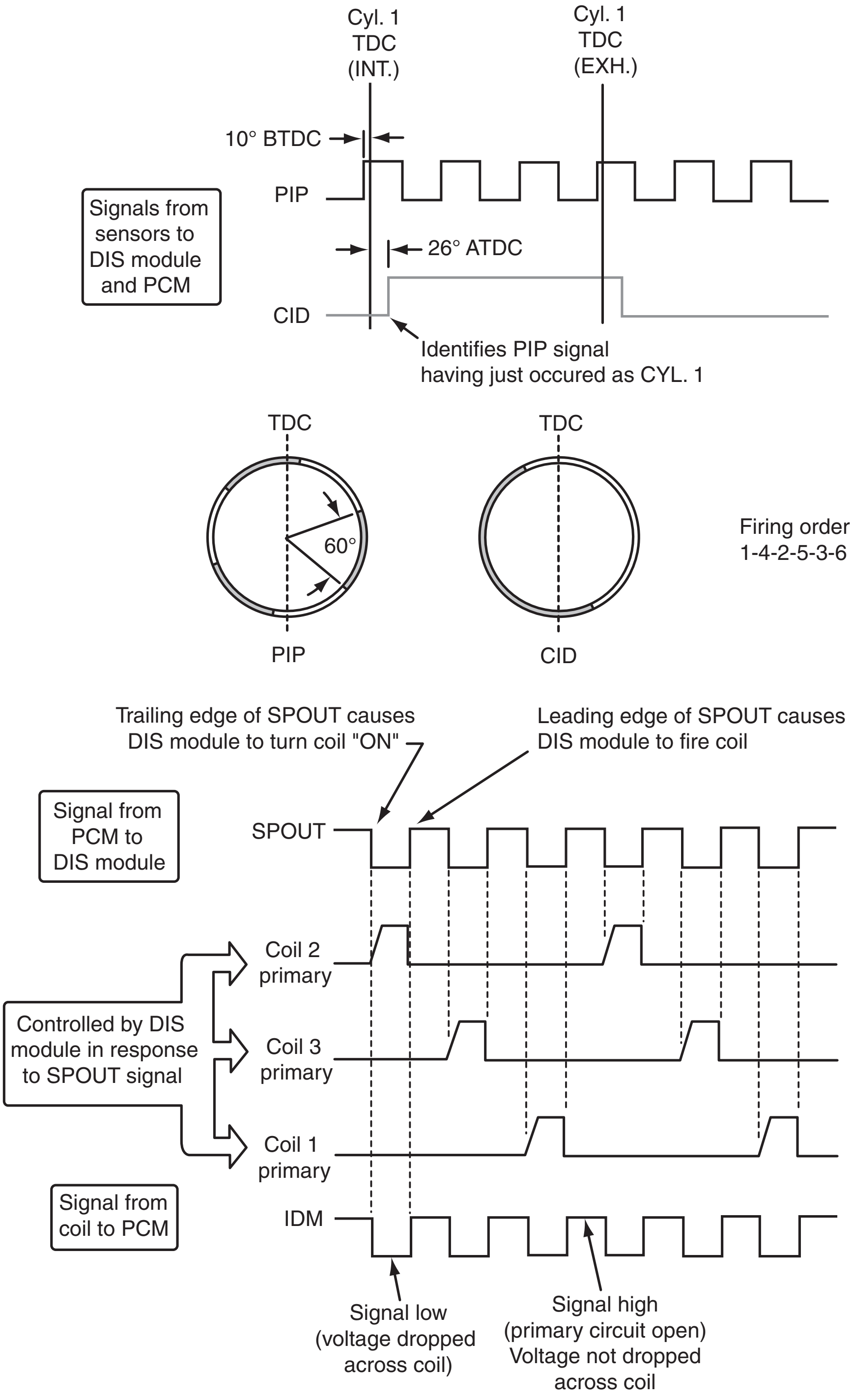

Cyl. 1
TDC
(INT.)
Cyl. 1
TDC
(EXH.)
10° BTDC
Signals from sensors to DIS module and PCM
PIP
26° ATDC
CID
Identifies PIP signal having just occured as CYL. 1
TDC
60°
PIP
TDC
CID
Firing order 1-4-2-5-3-6
Trailing edge of SPOUT causes DIS module to turn coil "ON"
Leading edge of SPOUT causes DIS module to fire coil
Signal from PCM to DIS module
SPOUT
Coil 2 primary
Controlled by DIS module in response to SPOUT signal
Coil 3 primary
Coil 1 primary
Signal from coil to PCM
IDM
Signal low (voltage dropped across coil)
Signal high (primary circuit open) Voltage not dropped across coil

Figure 13–46 DIS coil firing 3.0-L SHO and supercharged 3.8-L engines.

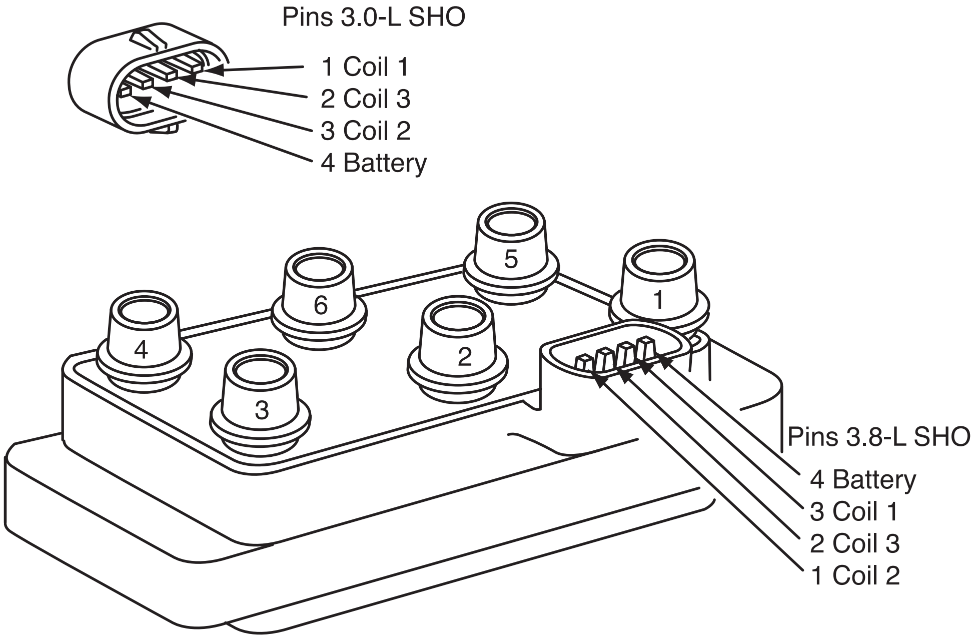


Figure 13–47 DIS coil pack, supercharged 3.8-L and 3.0-L SHO engines.

(Figure 13–47) builds a magnetic field while the DIS module waits for the next SPOUT leading edge. When the next SPOUT leading edge occurs, the DIS module opens coil 2's primary circuit and fires spark plugs 3 and 4.

The CID signal transition the DIS module waited for before it turned on coil 2 could have been a leading edge or a trailing edge, because either transition indicates that cylinder number 1 is at 26 degrees ATDC on either its power stroke or its intake stroke. Following the CID transition, the DIS module selects coil 2 because coil 2 fires spark plugs 3 and 4 simultaneously, and cylinders 3 and 4 are the next cylinders at TDC, one on its compression stroke and the other on its exhaust stroke.

Having opened the primary circuit and fired coil 2, the DIS module now waits for the next trailing edge of the SPOUT signal. When that comes, the module grounds coil 3. When the leading edge of the SPOUT signal next occurs, the DIS opens the primary circuit of coil 3, firing its two plugs. Then it turns coil 1 on and off in response to the next SPOUT signal from the PCM. Obviously, the PCM controls when the cylinders fire by the time it raises the SPOUT signal voltage, and it controls ignition coil dwell by controlling how long the SPOUT signal voltage is low.

Once the DIS module has identified the number 1 cylinder, a counter circuit in the module keeps track of the coil firing sequence. The DIS module continues to monitor the CID signal to verify its cylinder counting circuit. The PCM continues to use the CID signal while the engine runs to control injector pulsing.

2.3-L, Dual Plug DIS. The DIS on the 2.3-L engine works similarly to the 3.0-L SHO and the supercharged 3.8-L engines, but it has some unique features (Figure 13–48). Because the 2.3-L engine with DIS uses two spark plugs per cylinder (to achieve cleaner burning of the intake charge during combustion), the system has two separate coil packs: one on the right side of the engine and one on the left (Figure 13–49). The

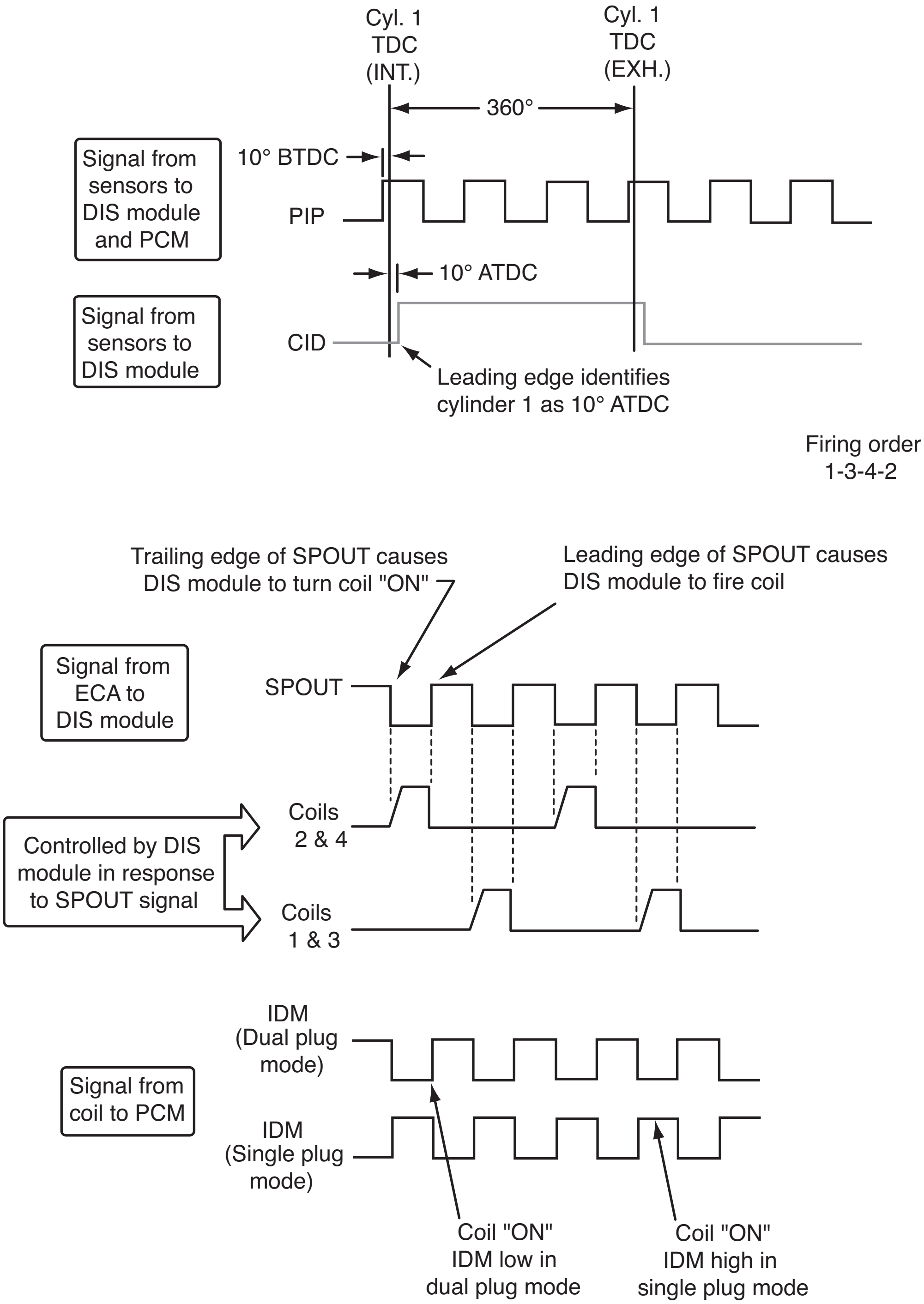

Cyl. 1
TDC
(INT.)
Cyl. 1
TDC
(EXH.)
360°
Signal from sensors to DIS module and PCM
10° BTDC
PIP
10° ATDC
Signal from sensors to DIS module
CID
Leading edge identifies cylinder 1 as 10° ATDC
Firing order 1-3-4-2
Trailing edge of SPOUT causes DIS module to turn coil "ON"
Leading edge of SPOUT causes DIS module to fire coil
Signal from ECA to DIS module
SPOUT
Coils 2 & 4
Controlled by DIS module in response to SPOUT signal
Coils 1 & 3
IDM (Dual plug mode)
Signal from coil to PCM
IDM (Single plug mode)
Coil "ON" IDM low in dual plug mode
Coil "ON" IDM high in single plug mode

Figure 13–48 DIS coil firing, 2.3-L, dual plug engine.

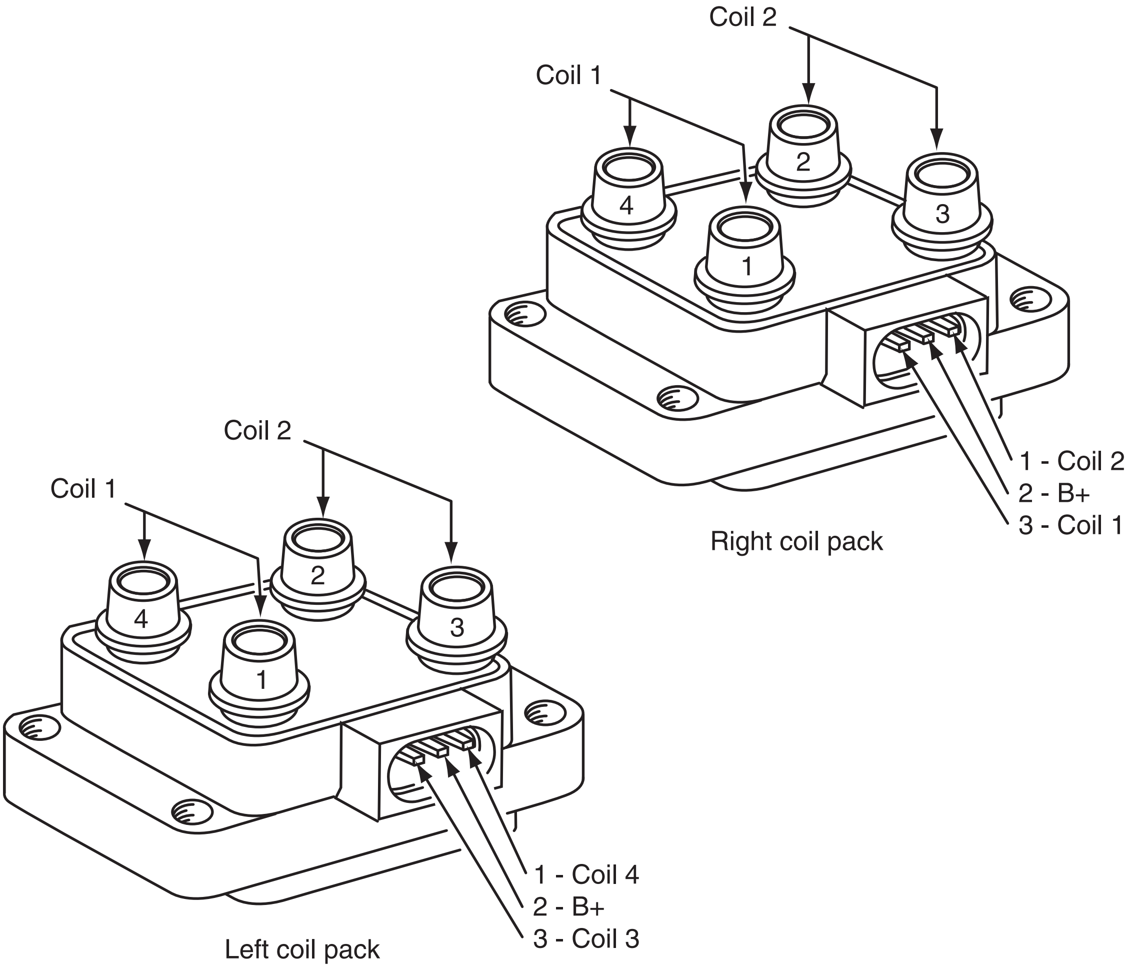


Figure 13–49 DIS coil packs, 2.3-L, dual plug engine.

right coil pack contains coils 1 and 2. Coil 1 fires the right-side spark plugs in cylinders 1 and 4 (Figure 13–50). Coil 2 fires the right-side spark plugs in cylinders 2 and 3. Coil 3 fires the left-side spark plugs in cylinders 1 and 4, while coil 4 fires the left-side spark plugs in cylinders 2 and 3.

After the engine starts, both plugs fire in each cylinder together: coils 1 and 3 fire together, with coil 1 firing right plugs 1 and 4 and coil 3 firing left plugs 1 and 4. During start-up cranking, only the right coil pack fires. The left coil pack is also turned off during heavy load, when there is a greater potential for detonation to occur.

The ignition module receives a Dual Plug Inhibit (DPI) signal from the PCM when the PCM wants the module to operate in single-plug mode. This is a 12-V signal that originates within the ignition module and then can be pulled low by the PCM (Figure 13–51). When the PCM wishes the module to operate in single-plug mode, it releases the ground, allowing the DPI signal to go high. The module responds by turning off the left

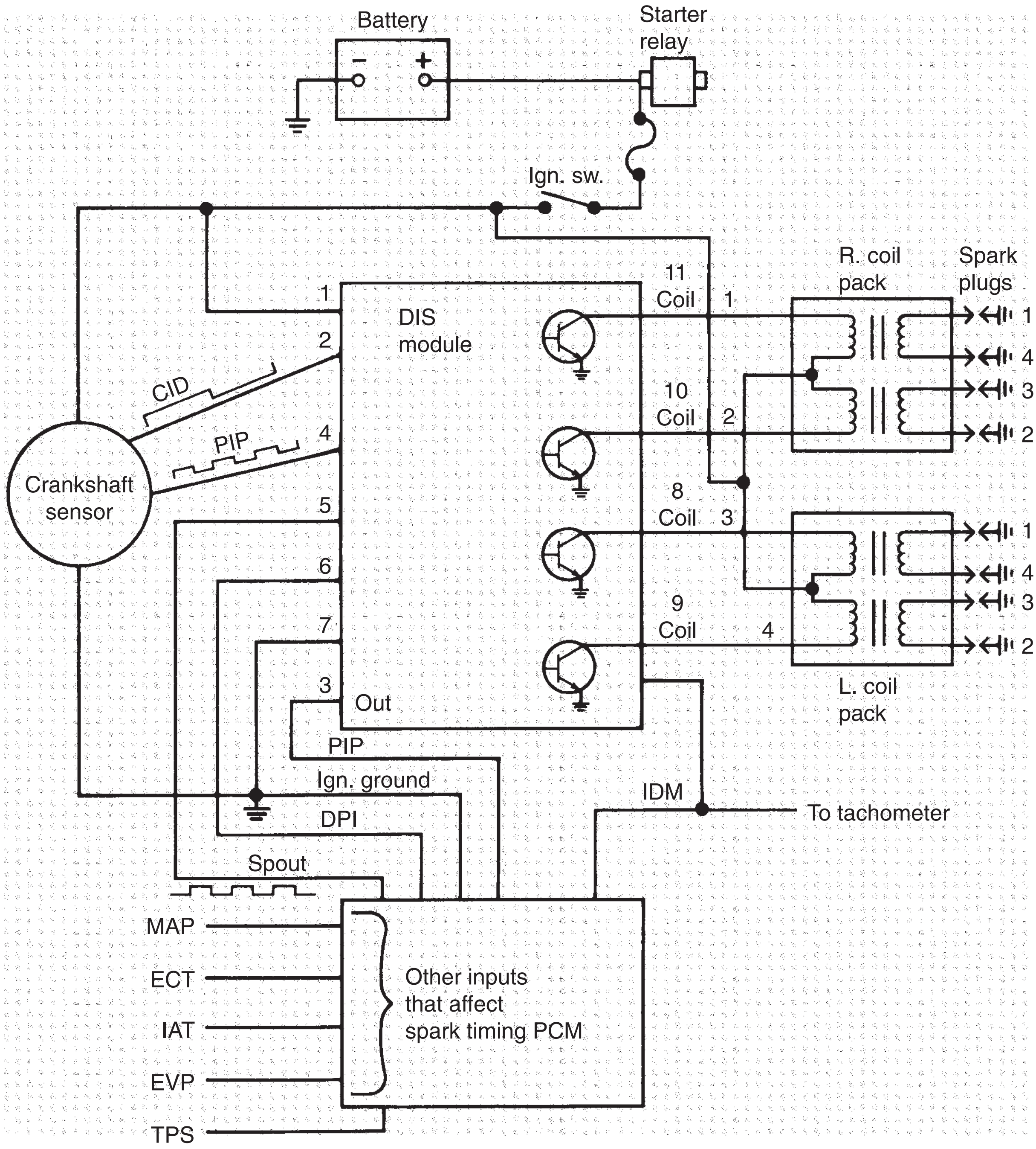


Figure 13–50 2.3-L, dual plug DIS schematic.

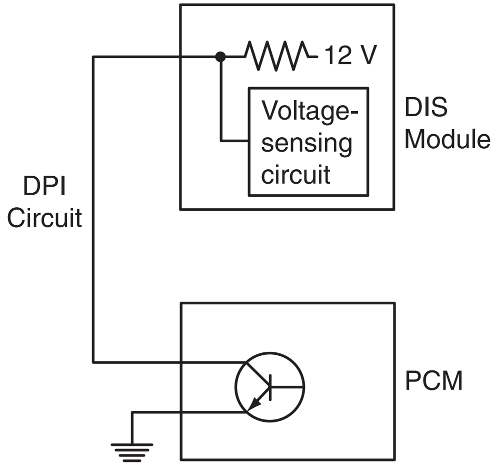


Figure 13–51 2.3-L DPI circuit.

coil pack. When the PCM wants the module to operate in dual plug mode, it grounds out the DPI voltage signal, thus pulling the DPI signal to zero volts. The module responds by operating both coil packs in unison.

As shown in Figures 13–46 and 13–48, when the SPOUT signal goes low, the primary coil circuit turns on; there is a large volt drop across the primary coil winding, so the voltage at the coil negative terminal, where the IDM originates, is near zero. Therefore, the IDM signal is low. When the SPOUT signal goes high, the coil primary circuit is open, and there is no volt drop across the winding; voltage at the coil negative terminal is battery voltage, and the IDM signal is high. While the 2.3-L, dual plug engine is cranked and the system is in DPI mode, the IDM signal is inverted (Figure 13–48). By monitoring the IDM signal, the PCM can tell whether the DPI command is being responded to.

Because the 2.3-L, dual plug engine in the EEC IV application did not use sequential fuel injection, the PCM did not need to monitor the CID signal; therefore, it is not sent to the PCM.

On either system, if when the engine starts cranking, the CID signal does not arrive at the DIS module, the module randomly selects the first coil to fire in response to a SPOUT signal. Once the first coil is selected, the other coils follow in their normal sequence. If the random choice is wrong—if the computer guessed wrong when selecting a coil—the engine will not start. Each time the starter motor stops and restarts the DIS module makes another random selection. When the random selection turns out to be the right coil, the engine will start. Since there are only two possibilities, it is unlikely that a great number of trials will be necessary on one of these systems.

If the SPOUT signal fails, the DIS module fires the coils in response to the PIP signal. Like the TFI-IV module, the DIS module has a current limiter circuit. Primary current is limited to 5.5 amps ± 0.5 amps.

Electronic Distributorless Ignition System

In 1991, Ford introduced a second-generation distributorless system known as the Electronic Distributorless Ignition System (EDIS) on the 1.8-L and 4.6-L passenger car engines and also on the 4.0-L light truck engine. This system is a waste spark ignition system, similar to Ford's DIS system, but the crankshaft and camshaft sensors are variable reluctance sensors (VRSs) instead of Hall effect sensors. These sensors, therefore, produce an AC voltage pulse for each tooth that they monitor.

The crankshaft sensor monitors 35 teeth on the harmonic balancer, one tooth spaced every 10 degrees of crankshaft rotation for a total of 36 teeth, minus one tooth to create a 20-degree space or blank spot. The blank spot informs the PCM of the position of the crankshaft, and then the PCM is able to count off the remainder of the crankshaft's rotation in 10-degree increments. This allows the PCM to calculate when each pair of pistons is approaching TDC. This information allows the EDIS ignition module to fire the correct ignition coil. The signal from the crankshaft sensor was originally called the VRS signal. Under OBD II standards, it is now referred to as the crankshaft position (CKP) signal.

The camshaft signal is used on the two sequentially fuel injected engines, the 1.8-L and

4.6-L passenger car engines. This signal allows the PCM to determine which stroke a given cylinder is on for purposes of pulsing the correct fuel injector. This sensor monitors one tooth per camshaft rotation and produces the camshaft position (CMP) signal.

The command signal from the PCM to the EDIS ignition module (which carries instructions as to when to fire each coil) is called *spark angle word* or SAW. This signal equates to the SPOUT signal in the TFI-IV and DIS ignition systems.

Base Timing Check

Both the DIS and EDIS ignition systems have fixed base timing, which is not adjustable. However, because a technician is expected to *check* base timing before performing the computed timing check (described in the "System Diagnosis and Service" section later in this chapter), Ford still provided a means to take the system to base timing. In the DIS ignition system, the technician simply pulls the shorting bar in the SPOUT circuit. Similarly, in the EDIS ignition system, the technician simply pulls the shorting bar in the SAW circuit. This shorting bar, when removed from its connector, opens the electrical circuit that it normally completes. When the shorting bar is removed, the engine runs at base timing. This shorting bar should always be reinstalled after testing is complete. For more information on the SPOUT/SAW connector, see the "System Diagnosis and Service" section later in this chapter.

Octane Adjustment

Because both the DIS and EDIS ignition systems have nonadjustable base timing, both systems also employ a circuit known as the *octane adjustment* circuit. This circuit contains a shorting bar that looks like the shorting bar in the SPOUT/SAW circuit. When the shorting bar is removed, the PCM calculates computed timing at 3 degrees to 4 degrees less than the original spark advance program calls for under a given engine operating condition. This allows the technician to correct for slight detonation problems. If the engine still detonates, the customer should be advised to use a fuel that is rated at a higher octane. When detonation occurs, this shorting bar may be left out of its circuit and put in the glove box of the vehicle. To differentiate between the shorting bar in the octane adjustment circuit and the shorting bar in the SPOUT/SAW circuit, wire colors should be checked and an electrical schematic should be used.

Knock Sensor Response. On systems using a knock sensor (KS), the strength of the knock sensor's signal is proportional to the severity of the spark knock. When a knock signal is received by the PCM, it retards timing one-half degree per engine revolution until the knock disappears.

Idle Speed Control

Three different systems are used for idle speed control (ISC) among various EEC IV applications.

Throttle Kicker. Throttle kicker is a vacuum-actuated device containing a diaphragm, a spring, and a plunger. It is mounted on the carburetor or CFI unit. On applications where the throttle kicker is used, normal idle speed is controlled by a conventional idle stop screw. However, when vacuum is applied to the diaphragm, the plunger extends and opens the throttle blade slightly to increase idle speed. It is sometimes referred to as a vacuum-operated throttle modulator (VOTM).

The PCM controls a solenoid that in turn controls vacuum to the throttle kicker. Part of the throttle kicker solenoid (TK solenoid) assembly is a normally closed vacuum valve. When the solenoid energizes, the vacuum valve opens, allowing vacuum to the throttle kicker. The throttle kicker is activated during the following operating conditions:

- when engine temperature is below a specific temperature

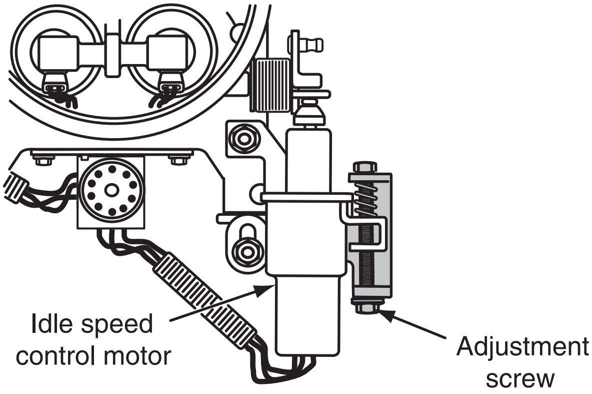


Figure 13–52 ISC motor assembly.

- when engine temperature is above a specific temperature
- when the A/C compressor clutch is engaged
- when the vehicle is above a specified altitude

DC Motor Idle Speed Control. The ISC motor is a small, reversible electric motor. It is part of an assembly including the motor, a gear drive, and a plunger (Figure 13–52). When the motor turns in one direction, the gear drive extends the plunger; when the motor turns in the opposite direction, the gear drive retracts the plunger. The ISC motor mounts so the plunger can contact the throttle lever. The PCM controls the ISC motor, changing the polarity applied to the motor's armature to control the direction it turns (Figure 13–53). When the idle tracking switch (ITS) opens (indicating closed throttle), the PCM commands the ISC motor to control idle speed. The ISC provides the correct throttle opening for cold or warm engine idle.

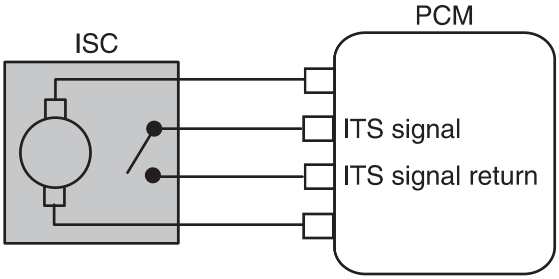


Figure 13–53 ISC motor circuit.

When the throttle opens and closes the ITS, the PCM commands the ISC motor to fully extend the plunger to function as a dashpot. In other words, when the throttle closes again during deceleration, the plunger prevents the throttle from closing completely. The pressure on the plunger opens the ITS, and the motor in turn retracts the plunger to the normal idle position. This delayed throttle closing allows additional air into the manifold while completely vaporizing fuel that has condensed on the manifold walls. The effect is to lean out an otherwise very rich mixture due to the sudden high vacuum condition that occurs on a deceleration.

With the ignition off, the PCM commands the ISC motor to retract the plunger fully, closing the throttle completely and preventing dieseling. Once the engine has completely stopped, the PCM commands the plunger to return to the fully extended position in preparation for the next engine start.

This assembly is very similar in concept to the one used by General Motors on its feedback carburetors and Cadillac DFI throttle body injection, except that the Ford ITS operates exactly in reverse of the GM unit. GM's is electrically closed at idle when the throttle lever depresses it and opens off idle.

Idle Air Bypass Valve Solenoid. An ISC solenoid is used on EEC IV multipoint fuel injection systems. The solenoid operates a normally-closed pintle valve that controls throttle bypass air (Figure 13–54). This bypass valve is attached so that when it is open, air passes from in front of the throttle blade through the pintle valve to the intake manifold side of the throttle. The PCM controls this valve by duty cycling the solenoid. Increasing the duty cycle's on-time increases the flow of bypass air around the throttle plate. The PCM cycles the solenoid so as to provide the proper air as required by the targeted idle RPM.

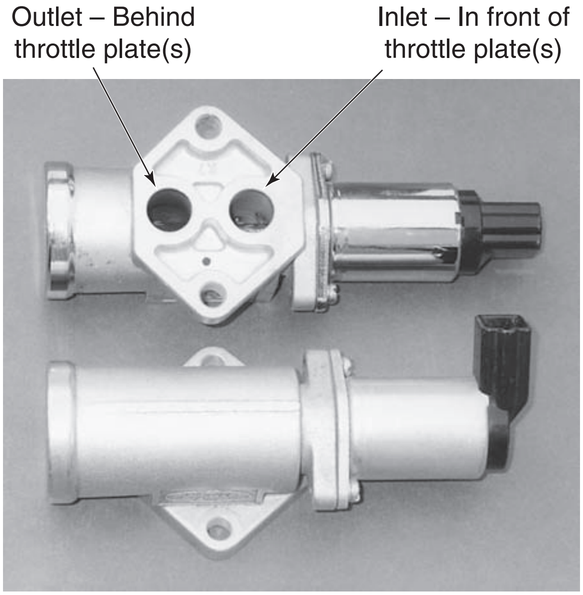

Outlet – Behind throttle plate(s)
Inlet – In front of throttle plate(s)

Figure 13–54 Throttle air bypass solenoid valves.

During a cold start, the PCM holds the idle air bypass solenoid valve at a 100 percent duty cycle (valve held wide open). During cranking, hot or cold, the bypass valve provides enough air that it is not necessary for the driver to touch the throttle. It also provides a throttle dashpot function as described previously.

Thermactor Air Management

The Thermactor system is the injection system that delivers air to the exhaust manifold or the catalytic converter to aid in the reduction of HC and CO (commonly referred to as a *secondary air injection system*). During operations requiring a rich air/fuel mixture, such as cold start-up or WOT, Thermactor air is dumped back into the atmosphere to avoid overheating the catalytic converter. One such condition for EEC IV and most other Ford electronic engine control systems is during engine idle. For this period, Ford tends to program the system for a rich idle mixture to maintain a good idle quality and prevent stalls.

EEC IV systems use one of two Thermactor systems. One is PCM-controlled and is discussed here. The other is a pulse injection system using the negative pressure between exhaust pulses in the exhaust manifold (most effective and most common on four-cylinder engines) to draw air from the air cleaner past check valves into the exhaust manifold. This system is sometimes called *Thermactor II* and is not PCM controlled.

Thermactor Air Bypass (TAB) and Thermactor Air Divert (TAD) Valves. The air pump runs constantly, driven by a belt. This pump supplies air to the Thermactor Air Bypass (TAB) valve, which either directs it to the Thermactor Air Divert (TAD) valve or dumps it to the atmosphere (Figure 13–55). The TAD valve can direct the Thermactor air either upstream to the exhaust manifold or downstream to the catalytic converter. The valves are activated by vacuum diaphragms controlled by PCM-controlled vacuum solenoids.

TAB and TAD Vacuum Solenoids. The TAB and TAD vacuum solenoids control whether vacuum is applied to the TAB and TAD valves. If the engine starts with a coolant temperature below 50°F (10°C), the PCM will leave the TAB solenoid circuit de-energized. Vacuum to the bypass diaphragm is blocked, and the diaphragm spring holds the valve in the down position, bypassing pump air to the atmosphere. Once engine temperature reaches 50°F, the PCM energizes the TAB solenoid by completing the ground path (Figure 13–56). Then vacuum is routed to the diaphragm, moving the TAB valve. Pump air is then directed from the TAB valve to the TAD valve. At the same time, the PCM energizes the TAD solenoid, and it directs vacuum to the TAD valve diaphragm. The TAD valve is moved to close off the passage to the catalytic converter and direct the air to the exhaust manifold. Once the coolant reaches approximately 190°F (88°C), the system goes into closed loop, the PCM de-energizes the TAD solenoid, and air is directed to the catalytic converter, behind the

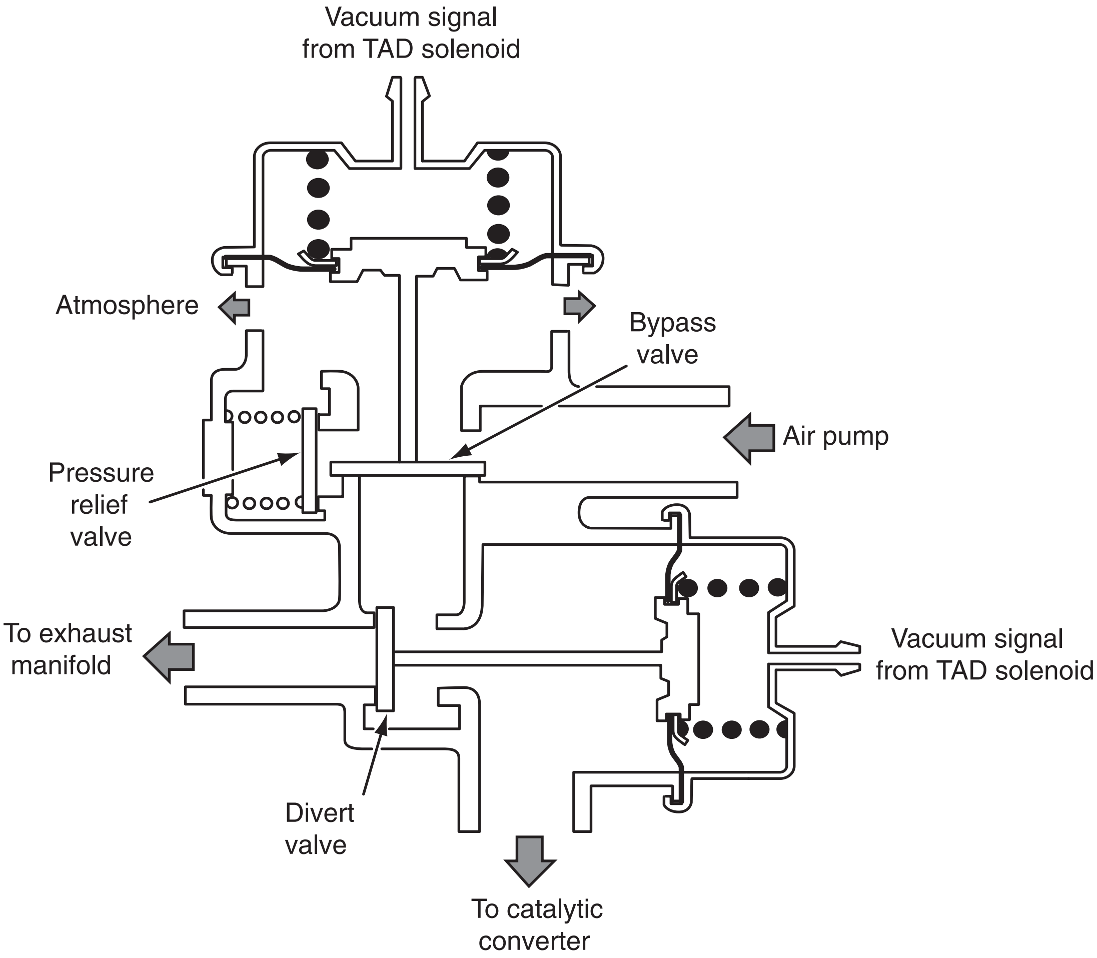


Figure 13–55 Combination of TAB and TAD valves.

NO_X reduction bed and upstream of the CO/HC oxidizing bed.

Certain operating conditions put the system back into bypass mode to protect the catalytic converter from overheating. These are:

- idle
- failure of the oxygen sensor signal to switch between rich and lean frequently enough (indicating that air/fuel mixture is not properly controlled or that the oxygen sensor is cooling or has become unresponsive with age and exhaust deposits)
- acceleration or WOT operating conditions

Canister Purge

Three types of canister systems are used on EEC IV vehicles. Some fuel-injected engines (both CFI and multipoint) use a constant purge system with no PCM control. Some engines use an in-line, PCM-controlled, solenoid-operated

Diagnostic & Service Tip: Closed-Loop Identification

Often a technician wants to know whether a computer-controlled system has gone into closed loop. While it is possible to check the oxygen sensor for its characteristic fluctuating low-voltage signal, on most vehicles including EEC IV Fords, the fastest way to check for closed loop is to see where the air injection system is routing the air. If the air is bypassed to the atmosphere or routed to the exhaust manifold, the system is in open loop. Only if the air is injected into the catalytic converter is the system in closed loop. This quick trick can save considerable time, but keep in mind that if there is anything wrong with the TAD solenoid circuit, or its slave diaphragm and vacuum circuit, the test may be inaccurate.

vacuum valve. The third uses a PCM-controlled solenoid controlling vacuum to a ported vacuum switch (a temperature-controlled vacuum valve), which in turn controls the canister purge (CANP) valve and an exhaust heat control valve.

In-Line Canister Purge Solenoid. This is a simple, normally closed, solenoid-controlled vacuum valve in the purge line connecting the charcoal canister to the intake manifold (Figure 13–57). Once the engine reaches normal operating temperature, the PCM will operate the solenoid on a duty cycle. The duty cycle depends on the vehicle's operating conditions. This allows the CANP to work at a controlled rate.

Canister Purge/Heat Control System. This system (which has very limited application) gets two-for-one from a PCM function. The PCM controls a normally closed, solenoid-operated vacuum valve. When the solenoid activates,

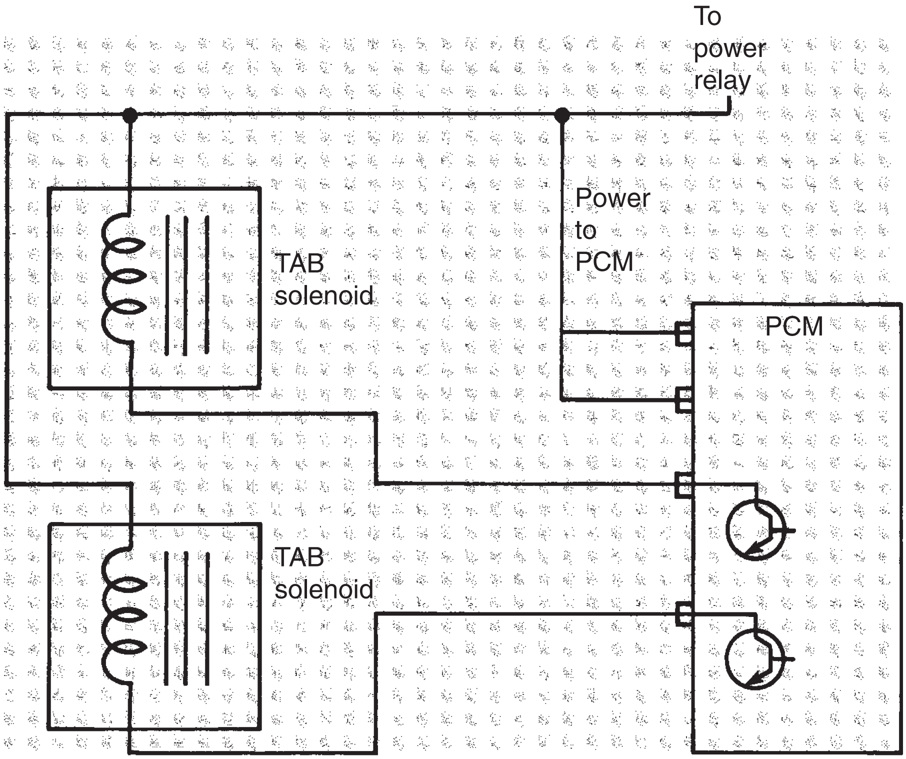


Figure 13–56 TAB/TAD solenoid control circuit.

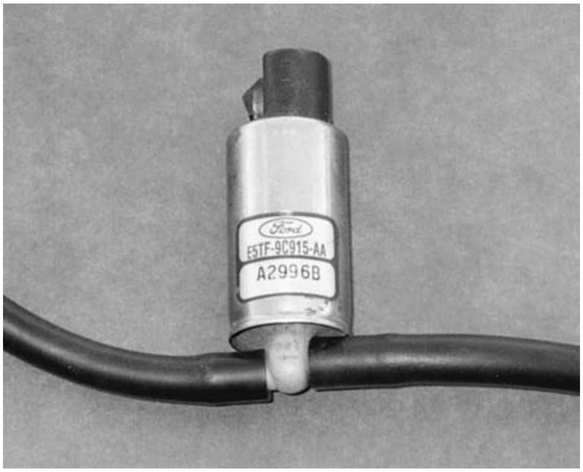


Figure 13–57 CANP solenoid.

vacuum is routed to the center port of a thermal vacuum switch (Figure 13–58). If the engine is cold, the thermal vacuum switch directs the vacuum to the top port, which connects to the heat control valve actuator. The actuator closes the heat control valve, forcing exhaust gas through the crossover passage, thereby warming the intake manifold plenum.

Once the engine warms, the wax pellet in the lower portion of the thermal vacuum switch expands and raises the valve. It closes the top port and opens the lower port to the vacuum signal. The heat control valve opens; then the purge control valve opens, allowing purging of the charcoal canister.

Exhaust Gas Recirculation Systems

The PCM controls four slightly different EGR systems, depending on engine application and vehicle.

EGR Control (EGRC) and EGR Vent (EGRV) Solenoids. This system is a carryover from EEC III; it is designed to control the amount of EGR flow (the EGR valve can be open, closed, or anywhere in between). An EGR valve position (EVP) sensor above the EGR valve tells the PCM where the EGR valve is. Two solenoids control the application and release of vacuum at the EGR valve (Figure 13–59). The normally closed **EGR Control (EGRC)** solenoid allows manifold vacuum to the EGR valve when energized. The normally open **EGR Vent (EGRV)** solenoid allows atmospheric pressure into the vacuum line when not energized.

To *apply* additional vacuum to the EGR valve, the PCM energizes both solenoids, thereby increasing the level of vacuum being used to pull the EGR valve open, causing it to open further. With both solenoids energized, the EGRC solenoid opens, allowing vacuum to be applied to the EGR valve, and the EGRV closes, allowing the system to hold vacuum. If this mode of operation is held long enough, the EGR valve will fully open.

To *maintain* the current vacuum level at the EGR valve and thereby maintain the current position of the EGR valve, the PCM energizes only the EGRV solenoid. With the EGRC solenoid de-energized, additional vacuum is not applied to the EGR valve, and with the EGRV solenoid energized, EGR vacuum is not vented to atmosphere, but instead is held within the EGR valve. That is, both solenoid-operated valves are closed and the current level of vacuum is trapped at the EGR valve. The PCM may choose to hold the system in this mode for extended periods of time as engine performance conditions permit.

To *release* some of the trapped vacuum from the EGR valve and thereby allow the EGR valve to close up further than it is, the PCM de-energizes both solenoids. The EGRC solenoid does not allow vacuum to be applied to the EGR valve, but the EGRV solenoid does allow vacuum to be released. If this mode of operation is held long enough, the EGR valve will fully close. The *release* mode is also the default mode if the system goes into its failure mode known as Failure Mode Effects Management (FMEM), as described later in this chapter, or if the system becomes otherwise incapable of controlling the EGR solenoids.

It is important to understand that the PCM does not operate these solenoids on either a

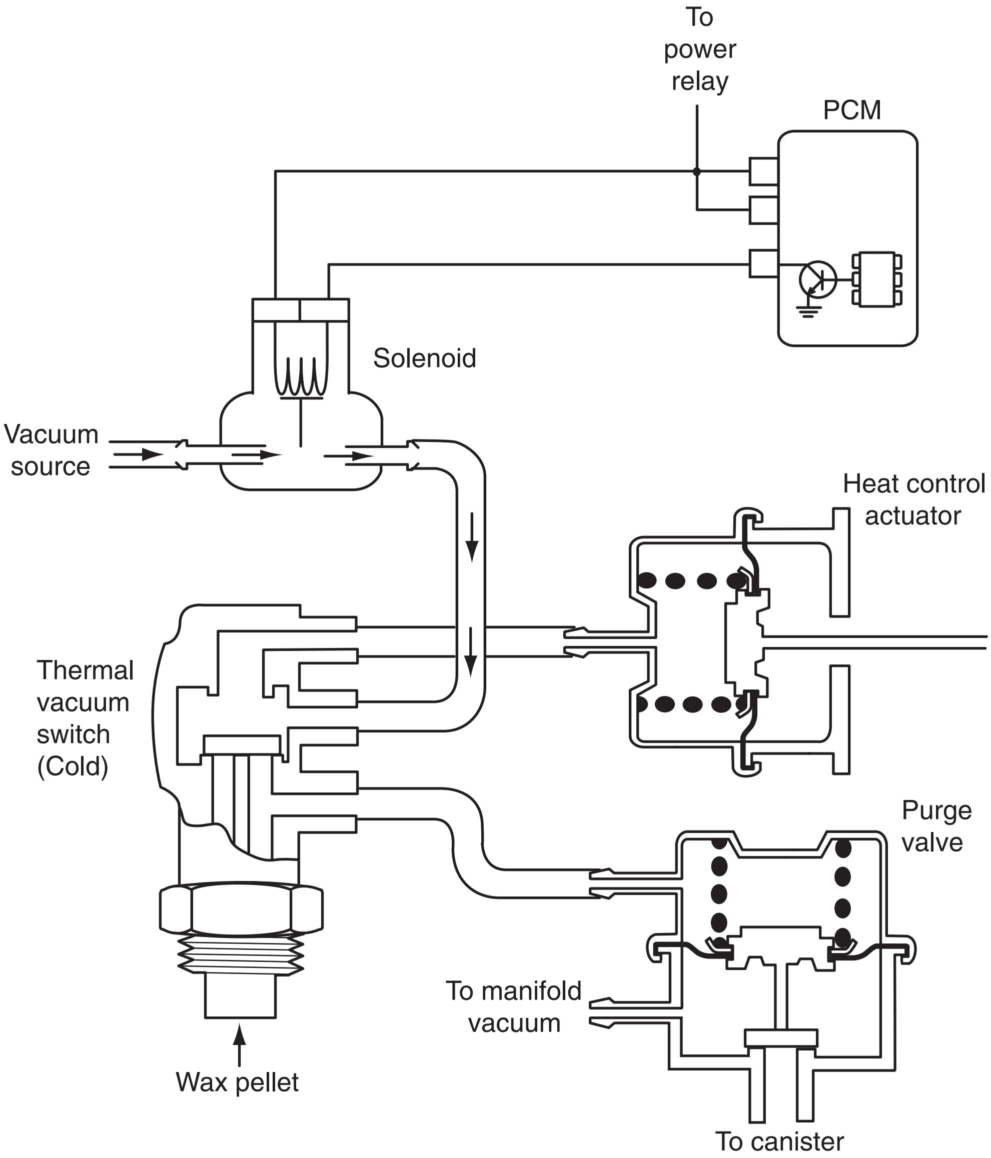


Figure 13–58 CANP/heat control system.

duty cycle or on a pulse width. Rather, the PCM modulates the solenoids on an *as needed* basis, similar to most vacuum-controlled cruise control systems. Ford engineers refer to this method of control as "dithering" the solenoids. Both solenoids cycle to achieve and maintain the desired EGR valve position. Throughout this, the EVP sensor provides a feedback signal to the PCM as to the current position of the EGR valve. Therefore, this is sometimes referred to as a *closed-loop EGR system*. This system allows the PCM more accurate control of the air/fuel

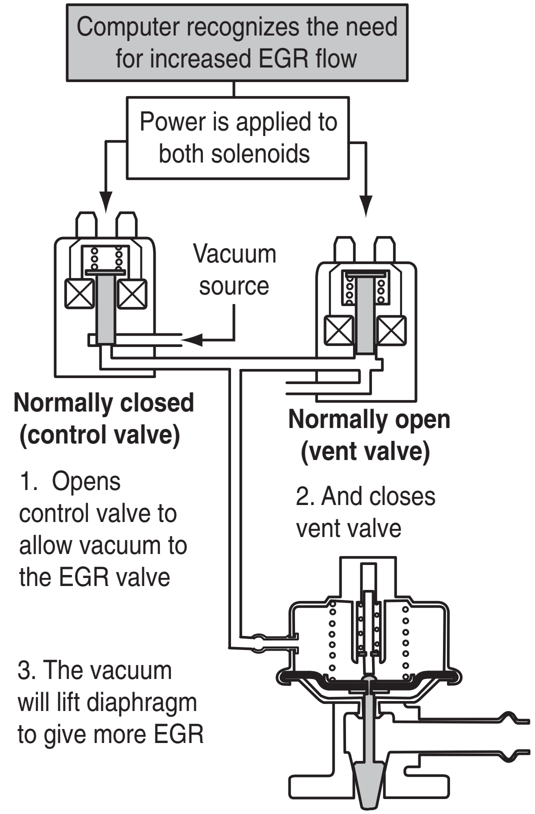

Computer recognizes the need for increased EGR flow
Power is applied to both solenoids
Vacuum source
Normally closed (control valve)
Normally open (vent valve)
1. Opens control valve to allow vacuum to the EGR valve
2. And closes vent valve
3. The vacuum will lift diaphragm to give more EGR

Figure 13–59 EGRC/EGRV solenoids.

mixture than a system that only assumes the EGR valve's position because of the role that these exhaust gasses play in affecting how much air gets into the combustion chamber. Additionally, this system allows the PCM to set fault codes during diagnostics if it has been tampered with, or if, for some other reason, it is not working properly.

EGR Shutoff Solenoid. This system uses one vacuum control solenoid operating like the vacuum control just described except that it uses ported vacuum instead. When the solenoid is energized, vacuum moves the EGR valve; when the solenoid is not energized, vacuum is blocked. In this system the EGR valve may or may not have an EVP sensor. Those with the sensor work like the EGRV and EGRC solenoids combined into one, while those without the sensor are not modulated. They are either open or closed.

EGR Shutoff Solenoid with Back-Pressure Transducer. This system, like the one previously described, uses one normally closed vacuum control solenoid. The strength of the ported vacuum signal to the EGR valve is controlled, however, by an exhaust back-pressure variable transducer. The transducer is tied into the EGR valve's vacuum supply line and controls an air bleed into the line. Pressure signals are connected to the transducer from the exhaust system. The back-pressure signal comes from a tap in the tube routing exhaust gas to the EGR valve. The control pressure signal comes from a point just downstream from the metering orifice, allowing exhaust into the EGR supply pipe. These two pressures act on a valve in the transducer to position it to control the air bleed.

When exhaust pressure is low and vacuum is high, the air bleed opens and causes the vacuum signal to the EGR valve to weaken. As exhaust pressure increases and manifold vacuum decreases, the air bleed becomes more closed and strengthens the vacuum signal to the EGR valve. This way, the transducer controls how far the EGR valve opens and the consequent EGR flow. This system does not employ an EVP sensor.

EGR Vacuum Regulator

This EGR control device, introduced in 1985, is simpler than the previous EGRC/EGRV control system. It works in a similar way, however. Like the EGRC/EGRV solenoid tandem, it allows the PCM to open the EGR valve to any degree through modulation of the signal. Since 1985, the EGR Vacuum Regulator (EVR) has become the standard EGR device used on most Ford engines.

The EVR is a single unit with two vacuum ports (Figure 13–60). The lower port connects

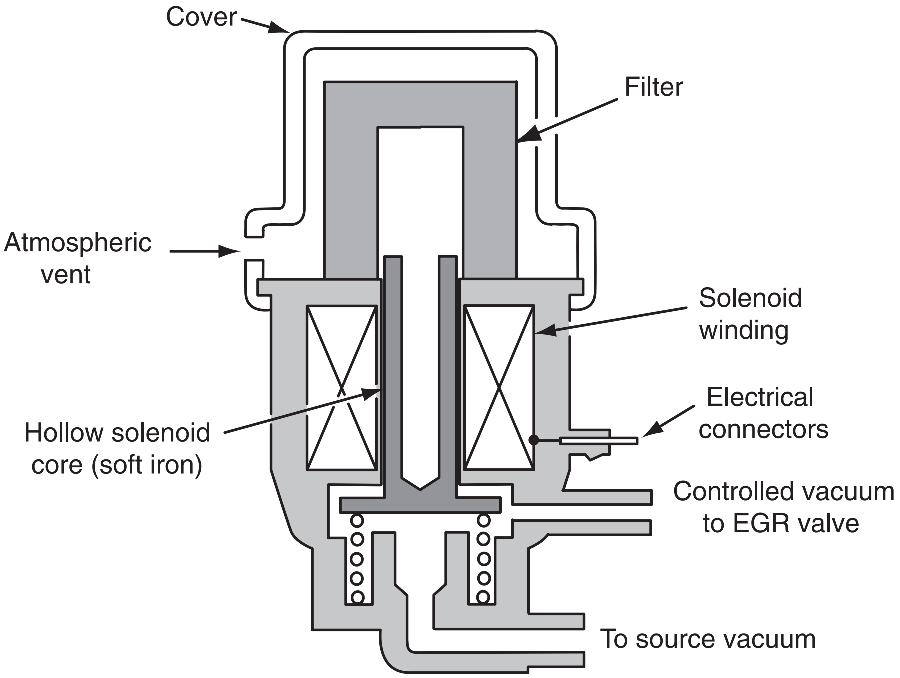


Figure 13–60 EVR.

to either manifold or ported vacuum, depending on which engine is in the vehicle. The upper port connects to the EGR valve. The vented cover allows air to flow through the filter and down the hollow, electromagnetic core. This allows atmospheric pressure to be present above the metal disk at the bottom of the core at all times. The disk is held against the bottom of the core by a weak spring. When the engine runs and the EVR is not energized, engine vacuum creates a low-pressure area below the disk. Because of this pressure differential, the spring cannot hold the disk against the bottom of the core tightly enough to keep atmospheric pressure from filling the vacuum chamber. With atmospheric pressure in the vacuum chamber, of course, the EGR valve closes.

When the PCM wants to open the EGR valve, it grounds the EVR. The magnetic field produced in the coil pulls the metal disk tightly against the bottom of the core, sealing off the chamber below from atmospheric pressure. Engine vacuum is then applied to the EGR valve. By controlling the EVR on a duty cycle, the PCM can control the percentage of time that the EVR is applying vacuum to the EGR valve (energized) versus the percentage of time that the EVR is releasing vacuum from the EGR valve (de-energized). Increasing the percent of duty cycle on-time ultimately opens the EGR valve more.

The EVR is often referred to as a solenoid. Because its electromagnetic core does not move, it is really not a solenoid but rather a simple electromagnet.

Torque Converter Clutch Control

Some Ford automatic transmissions such as the A4LD, AXOD, 4EAT, and E40D employ a PCM-controlled torque converter lockup clutch. In each case, the PCM controls the converter clutch with a solenoid in the transmission

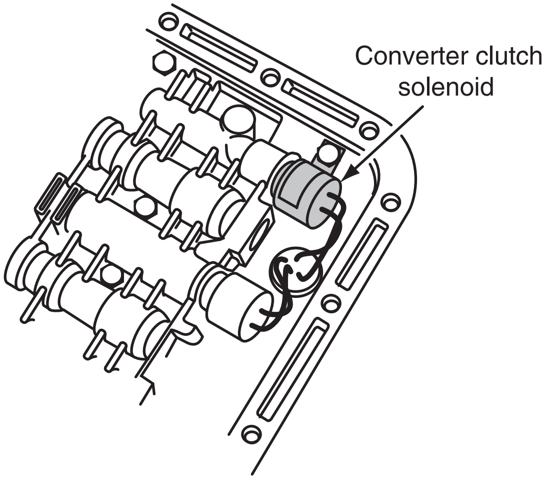


Figure 13–61 Torque converter lockup clutch solenoid.

(Figure 13–61). This solenoid moves a valve in the transmission valve body, which, in turn, routes transmission fluid under pressure into the torque converter and applies the lockup clutch.

The hydraulic circuitry applying the torque converter lockup clutch varies slightly among the different transmissions, but they work similarly. Figure 13–62 shows the hydraulic clutch apply circuit for the E40D transmission in the clutch-released mode. Line pressure to the converter clutch regulator valve feeds oil under pressure to the converter clutch control valve. With the converter clutch control valve in the right position as shown, line pressure oil is fed into the converter through the release passage between the transmission input shaft and the stator support. This introduces the oil into the converter on the engine side of the converter clutch plate. The pressure forces the clutch plate away from the engine side of the converter housing. The oil then flows over

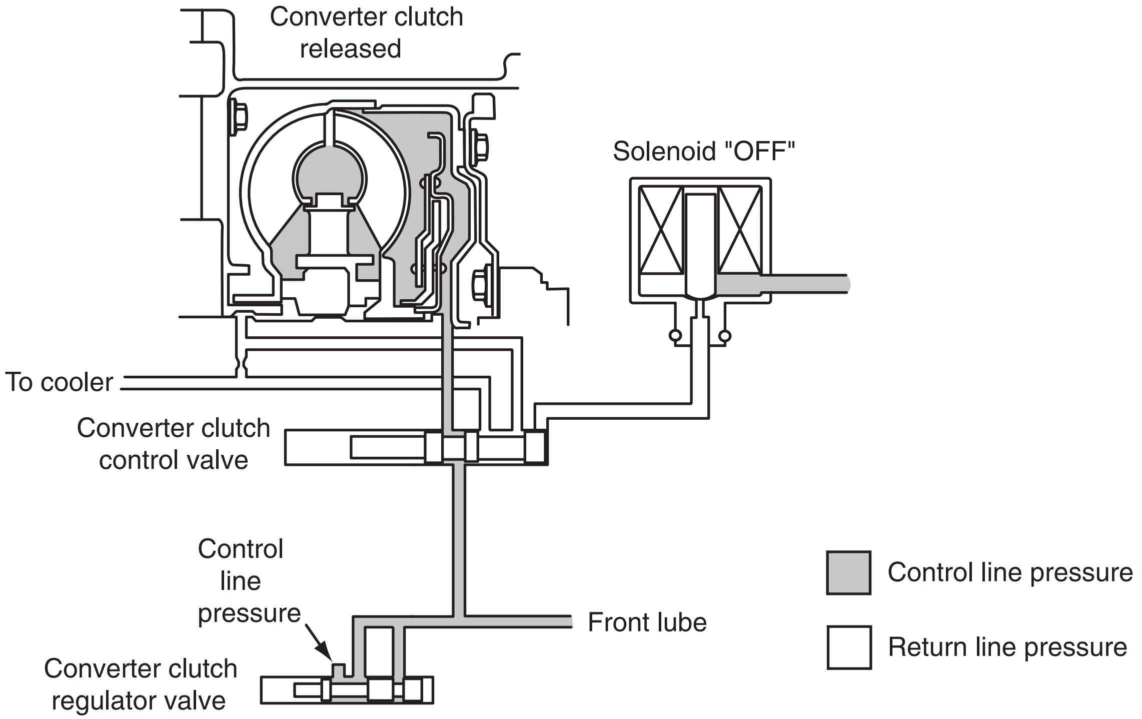


Figure 13–62 Torque converter lockup clutch released.

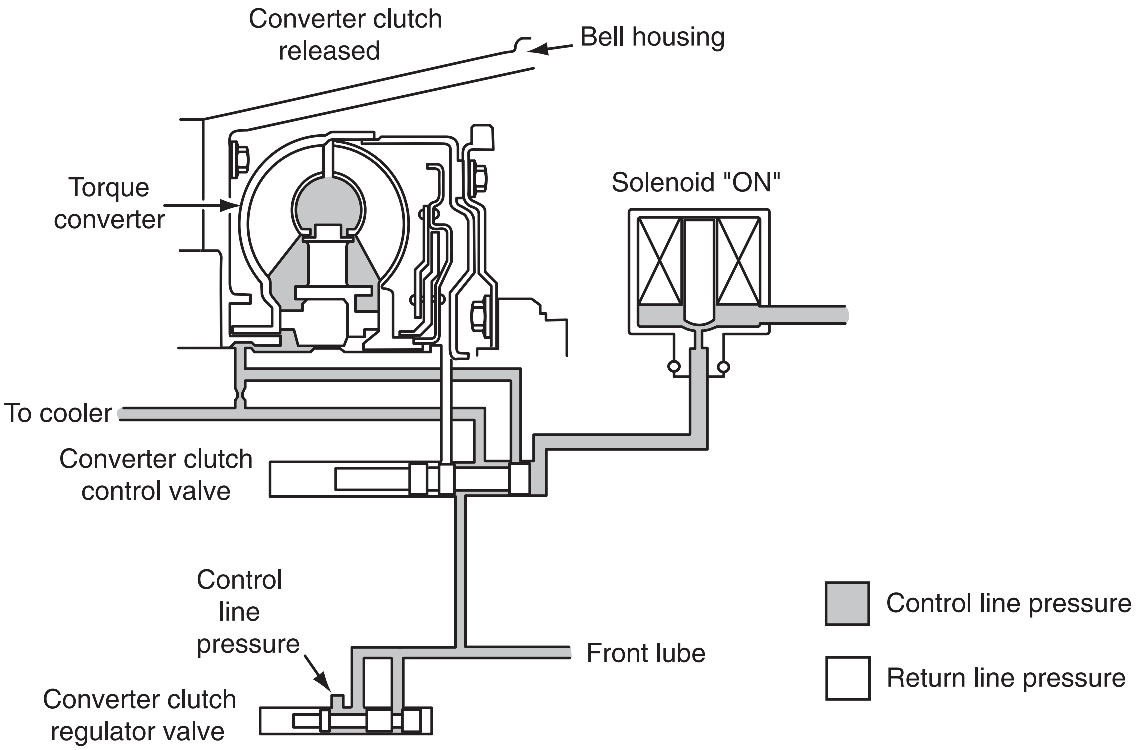


Figure 13–63 Torque converter lockup clutch applied.

the clutch plate at its circumference and exits the converter through the apply passage between the stator support, and then flows to the transmission oil cooler.

When the PCM energizes the converter clutch solenoid (Figure 13–63), line pressure is applied to the right end of the converter clutch control valve. It then moves left. This reroutes the oil under pressure coming from the converter clutch regulator valve. Line pressure oil now feeds into the converter through the apply passage. With the transmission oil introduced into the converter on the transmission side of the clutch plate, the pressure must flow over the circumference of the clutch plate to get to the exhaust passage and exit the converter. This moves the clutch plate toward the engine side of the converter housing. As the friction material at the outer circumference of the clutch plate contacts the machined surface of the converter housing, it seals off the flow of oil to the exhaust passage. With no pressure on the engine side of the clutch plate and line pressure on the transmission side, the converter clutch plate is forced against the converter housing with enough force to lock it up and drive the transmission input shaft at engine speed.

There are slight variations in the torque converter clutch control strategy, depending on the engine and transmission, but in general the following conditions must exist for the PCM to apply the torque converter clutch:

- engine warmed up to normal operating temperature
- engine not under heavy load
- part throttle cruise
- engine within a predetermined RPM range
- vehicle above a predetermined speed

The solenoid will deactivate when:

- The brake on/off (BOO) switch indicates the brakes are applied.
- The TPS indicates WOT.
- There is severe deceleration.

Turbocharger Boost Control Solenoid

Turbocharged 2.3-L engines with EEC IV control employ a PCM-controlled boost control solenoid that allows boost pressure to rise from the normal 10 PSI to as much as 15 PSI. Boost pressure is controlled by a wastegate that opens at a specified pressure, allowing some exhaust to bypass the exhaust turbine wheel, thus controlling the amount of boost pressure. The wastegate is controlled by a spring and diaphragm assembly (an actuator). Intake manifold pressure is routed to the actuator diaphragm. At the predetermined pressure, the diaphragm compresses the spring, moving a rod opening the wastegate.

If the PCM is satisfied with the current driving conditions, it activates the normally closed solenoid and cycles it at 40 Hz. When the solenoid activates, it bleeds off pressure from the wastegate actuator and allows a higher intake manifold pressure before the wastegate opens.

A/C and Cooling Fan Control

Some engine applications use a separate electronic control module to control the A/C compressor clutch and the engine cooling fan (or fans). Others, typically rear-wheel-drive vehicles with traditional "north–south" mounted engines and belt-driven cooling fans, use a relay to disable the A/C clutch during WOT operation.

A/C and Cooling Fan Electronic Module. The module (Figure 13–64) is usually located in the passenger compartment. It gets input information from:

- the PCM (WOT signal)
- a coolant temperature switch (which closes at 221°F [105°C])
- the brake switch (brakes applied)
- the A/C switch (A/C on)

The module has a ground terminal and gets power from the battery through the ignition switch.

When the A/C switch is on (assuming the ignition is also on), the module provides power to the compressor clutch. During WOT operation, the PCM signals the module, which then disables the A/C clutch by deactivating it. If the WOT condition continues, the clutch stays disabled for about 30 seconds before normal A/C operation resumes. If the coolant temperature is below 221°F, the module also disables the engine cooling fan in response to the WOT signal. If the coolant switch is closed, the module overrides the WOT signal from the PCM by refusing to disable the cooling fan.

If the vehicle has automatic transmission and power brakes, depressing the brake pedal signals the module to disable both the A/C clutch and the cooling fan for 5 seconds. This is to prevent an engine stall from the load combined with the suddenly closed throttle.

Wide-Open Throttle A/C Cutout Relay. The normally closed WOT cutout relay is in series with the A/C switch and the clutch coil. During WOT operation, the PCM grounds the WOT relay coil. The relay opens and thus disables the A/C clutch.

Engine Fuel Injector Cooling Tube

In 1987, the 4.9-L, six-cylinder, in-line engine was introduced with multipoint fuel injection instead of a feedback carburetor. Because the 4.9-L is not a cross-flow engine (the flow of gasses does not enter as intake on one side and leave as exhaust on the other), the injectors are located just above the exhaust manifold. This exposes the injector and its connecting fuel line to much more heat than on most systems, particularly during the hot soak following a hot engine shutdown. Exposing the injector to so much heat can result in fuel vaporization in the injector and

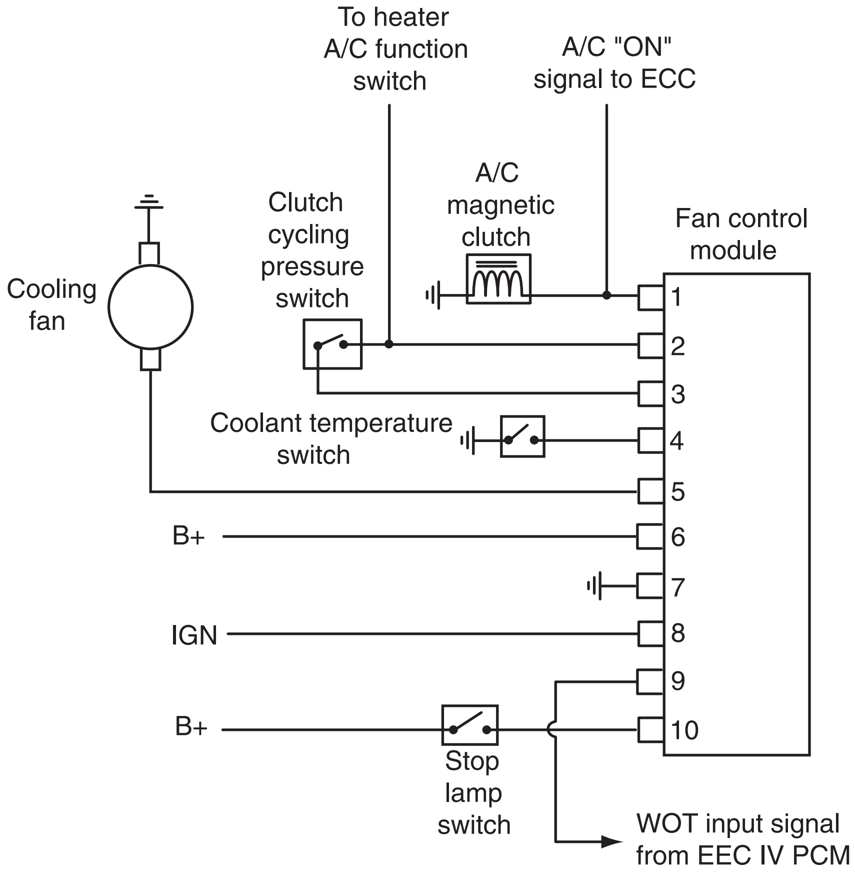


Figure 13–64 A/C and radiator fan control module.

adjacent fuel line (vapor lock) or even seizing of the injectors. Either condition could result in hard starting, rough running after start-up, or no start at all. To prevent this, an injector cooling system was added to the 4.9-L engine.

A tube runs almost the entire length of the engine, just above the injectors. Jets from the tube point to each of the first five injectors (injector 6 is not as exposed to exhaust manifold heat). A small blower blows air into the tube. The far end of the tube is closed so the cooling air is directed at the injectors through the jets. The fan is powered by an injector blower relay controlled by a module. This module is connected to a temperature-sensitive switch attached to the fuel rail. If the engine is shut down with a rail temperature of 170°F (77°C), the switch triggers the module, which turns on the fan. The module allows the fan to run for a maximum of 15 minutes. It turns the fan off if the temperature switch opens or if the ignition is turned on before the 15 minutes have elapsed. This system is not part of, nor is it controlled by, the EEC IV system. It does, as we have seen, affect start-up and driveability after a hot soak.

Shift Light Indicator

Some EEC IV–controlled vehicles with manual transmissions feature a shift indicator light on the instrument panel to indicate to the operator the best time to shift to the next higher gear to optimize emissions quality. To a lesser extent, this also indicates the best shift point for fuel economy. The PCM uses information concerning engine speed, manifold vacuum, and engine temperature to control the light. When the PCM sees an engine speed greater than 1800 RPM with a light engine load, it grounds the indicator light circuit. The PCM will not turn on the light while the coolant temperature is low. When the transmission goes into top gear, a switch in series with the PCM and the indicator light opens to prevent the light from coming on again.

Integrated Vehicle Speed Control

Beginning with 1986 Ford Taurus and Mercury Sable vehicles, the speed control function (cruise control) was integrated into the functions under the control of the PCM. This feature, added to the Crown Victoria in 1988 and to the Thunderbird in 1989, was known as Integrated Vehicle Speed Control (IVSC). (Ford engineers discontinued the use of the IVSC system in the 1991 model year as the demand for PCM terminals continued to grow.) If the IVSC function is turned on, the PCM will control how much vacuum is applied to the servo through two solenoids. The speed control vacuum control (SCVAC) solenoid is normally closed; it is energized by the PCM to apply vacuum to the servo, which in turn pulls the throttle open. The speed control vent (SCVNT) solenoid is normally open and, when de-energized, allows servo vacuum to be vented, thus allowing the throttle to close. Modulation of these two solenoids is identical to the EGRC and EGRV solenoids described in greater depth previously in this chapter. To use the speed control function, the driver communicates with the PCM through the speed control command switches (SCCS) located on the steering wheel.

Top Speed Limiting

Since 1988, some vehicles with the 5.0-L engine have included a top speed limit. The PCM is programmed to control maximum vehicle speed to a value within a rating on the vehicle's original equipment tires. The PCM achieves this by reducing the fuel injectors' pulse width once the specified vehicle speed is reached.

Programmed Ride Control. Beginning in 1987, certain Fords were equipped with a Programmed Ride Control (PRC) system. A switch on the instrument panel allows the operator to select either a plush or a firm ride. The shock absorbers have adjustable dampening valves, which are adjusted by rotating a small shaft extending up to the top of each shock absorber. A small electric motor mounted on top of each shock absorber turns the shaft. The motor is controlled by a PRC module. If, while operating in the plush mode, certain operating conditions occur, the module will automatically adjust the shock absorbers to the firm position. Some of the information that identifies those conditions is supplied to the PRC module by the EEC IV PCM.

Information supplied directly to the PRC module from sensors includes:

- hard braking—supplied by a pressure switch on the brake system
- hard cornering—supplied by a sensor on the steering shaft

Information supplied by the EEC IV PCM includes:

- more than 90 percent of WOT
- speeds above 83 miles per hour

✔ SYSTEM DIAGNOSIS AND SERVICE

One of the outstanding features of the EEC IV system is its self-diagnostic capability. The diagnostic features that are programmed into the EEC IV PCM, combined with the diagnostic procedures in the service manual, are very effective if the procedures are performed by a knowledgeable technician. These procedures may seem confusing at first because of their extent and complexity, but studying and practicing the procedures make them a powerful and effective tool in diagnosing EEC IV system complaints.

Malfunction Indicator Light

Beginning with a limited number of vehicles in 1987, Ford began equipping its vehicles with a malfunction indicator light (MIL). By the 1988 model year, most Ford vehicles incorporated a MIL for diagnostic purposes. The MIL is located on the instrument panel; it is used by the PCM to alert the driver to a fault within the EEC IV system. During self-testing of the EEC IV system, the MIL will also blink out the diagnostic trouble codes (DTCs).

Diagnostic Routines

The Ford engine performance diagnostic service manual, known as *Shop Manual Volume H*, or *H Manual* for short, contains a section called **Diagnostic Routines.** As with any system, the first step of diagnosis is to verify the driveability complaint or symptom. Then the technician should always begin by looking up the symptom in the charts in the Diagnostic Routines portion of the service manual. The charts in this portion reflect the likely order of probable problem areas for each symptom encountered, according to Ford engineers. For example, for some symptoms, EEC IV system diagnostic procedures are high priority. For other symptoms, EEC IV system diagnosis is much farther down the list, and other items are recommended as priority checks, such as cooling system checks or other basic engine checks.

EEC IV Equipment Hookup

One of the advantages in EEC IV system diagnosis is that, while a scan tool may be used to perform all diagnostic procedures (and is recommended), Ford engineers also provided a means for the technician to perform all self-tests and functional tests using manual methods. Of course, the only feature that cannot be accessed by manual methods is the data stream.

Both the manual methods and the scan tool utilize the self-test connector found in the engine compartment, known under OBD II standards as the diagnostic link connector (DLC). While the DLC was designed for Ford's **Star Tester** and Super Star II Tester (Ford's early scan tools), it will also work with Ford's New Generation Star tester (NGS) and Worldwide Diagnostic System (WDS) as well as aftermarket scan tools. In fact, some aftermarket scan tools allow the technician to select a Super Star II Tester emulation mode in addition to the engine test mode shown in the scanner's menu. This allows the technician to connect to and test electronic systems other than what may appear in the scanner's menu—for example, Ford's electronic suspension system. Whereas most modern scan tools prompt the technician when interaction is required during self-test procedures, the Super Star II Tester emulation mode does not do this; this is similar to using Ford's Super Star II Tester or manual methods. As a result, the technician must be familiar with Ford diagnostic concepts to use the Super Star II Tester emulation mode.

The following procedures describe the applicable manual methods. Understanding the manual methods allows the technician to comprehend what a scan tool does in order to interact with this system.

Slow Codes and Fast Codes

DTCs may be read by the pulsing of an analog meter's swing needle, the pulsing of an LED on a scan tool, or the pulsing of the MIL. Ford refers to these pulses as "slow codes." For example, a pulse, a pause, and a pulse would equate to a DTC 11. Two pulses, a pause, and three more pulses would equate to a DTC 23. All Ford EEC IV PCMs are capable of producing slow code output. Both the Ford Star Tester and the Ford Super Star II Tester are capable of reading slow codes, as is the NGS.

When the EEC IV PCM is ready to deliver DTC output, the first codes received are referred to as "fast codes." These codes imitate the slow codes exactly, but are pulsed at 100 times the speed of the slow code pulses. They are followed by the slow code output. The fast codes are designed to be interpreted by a scan tool and cannot be read when using manual methods. They appear as a flicker of the scan tool's LED or of the MIL. On an analog voltmeter, the fast codes are seen as a very short sweep of the needle. All EEC IV PCMs, except a few of the very earliest ones, produce fast code output. Ford's Super Star II Tester and NGS are capable of interpreting fast codes, as are most aftermarket scan tools.

EEC IV Self-Test Connector

The DLC (self-test connector) in the engine compartment is used to initiate (or trigger) the various tests. It may also be used with an analog voltmeter, if desired, to read code output, or the MIL may be used for this purpose. The primary DLC contains six female spade terminals. Similar connectors associated with other systems, including the antilock brake system and the electronic suspension system, may be found elsewhere on the vehicle, but only the EEC IV system DLC has an extra single terminal protruding from the same harness. This extra terminal is called *Self-Test Input* or *STI;* self-tests are triggered by grounding this terminal. A scan tool grounds the STI terminal internally when a self-test is selected from the menu.

If the primary six-terminal DLC is held facing you and its overall shape (which is shaped almost like an arrow) is pointing upward (with the two terminals on top and the row of four terminals on the bottom) (Figure 13–65), its terminals can be numbered in the same manner that you would read a book: left to right and top to bottom. DLC terminal 2 (known as *Signal Return* or *SIG RTN*) is connected to the ground side of the sensors; it connects to PCM terminal 46 and then is grounded through the PCM. A short jumper wire can be easily made with a male spade terminal on each end, and then used to connect Signal Return to STI in order to trigger any of the self-tests.

To count code output from the PCM, simply count flashes of the MIL. If the vehicle is an earlier model that does not have an MIL (or if you prefer not to use the MIL), you may connect an analog voltmeter between the battery and

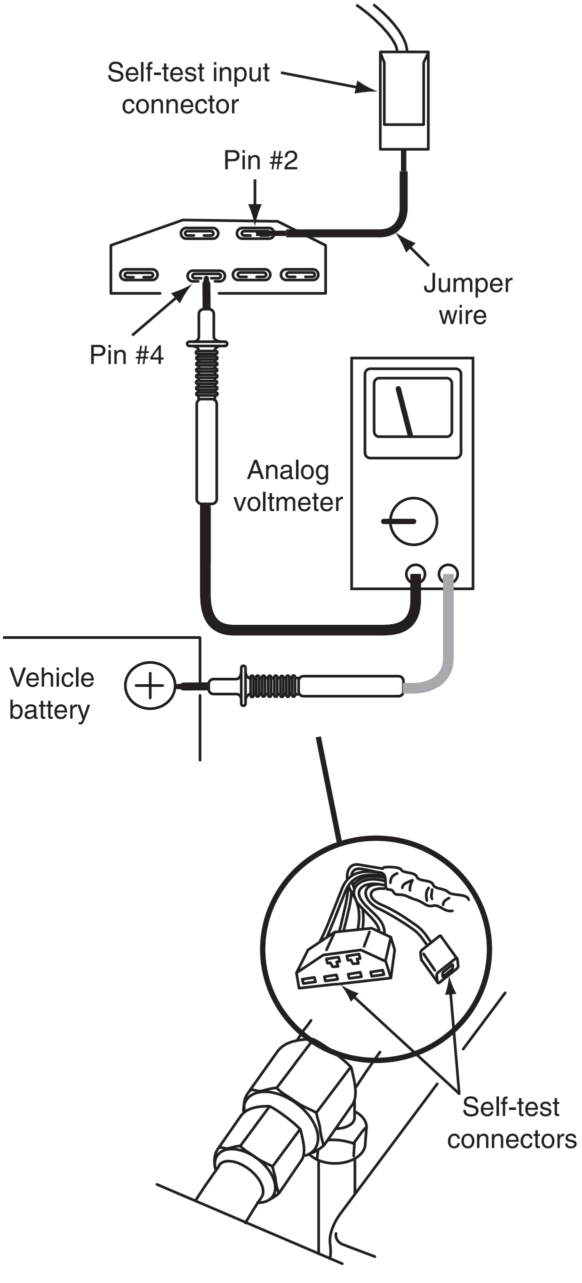


Figure 13–65 Voltmeter connection to self-test connector.

terminal 4 of the DLC, known as *Self-Test Output* or *STO.* Make up a short second jumper wire with a male spade terminal to connect to STO, and use it to connect the voltmeter's negative lead to STO. The voltmeter's positive lead should be connected to the battery positive terminal. When the PCM is ready to count code output on terminal 4, it will complete the ground path to energize the voltmeter in pulses, as if the voltmeter were an output actuator. Count the meter pulses to interpret the code. It is acceptable to connect a DVOM (on a DC voltage scale) or a logic probe to STO for the purpose of counting code output, although code output pulses are difficult to interpret with the DVOM unless the DVOM has a bar graph display.

CAUTION: *Do not connect a standard test light to STO!* It will draw more current than the PCM's output driver in this circuit is designed to handle. As a result, the PCM will be damaged and will have to be replaced before code output can be obtained with any of these methods, including with the use of a scan tool or through the MIL. Also, when using either an analog meter or a DVOM, verify that the meter is not set to an amperage scale and verify that the leads are not connected to an amps jack. Ammeters operate effectively as a jumper wire and will also destroy the PCM's circuitry.

EEC IV Engine System Performance Code Pulling Procedural Concepts

Four procedures are associated with code pulling on an EEC IV application.

Key On, Engine Off Self-Test. The first procedure is called a key on, engine off (KOEO) self-test. The resulting DTCs are hard faults and are known as *KOEO on-demand faults.* These are the first DTCs that should be tested through pinpoint testing according to the appropriate flowchart.

Key On, Engine Running Self-Test. The second code pulling procedure is to perform a key on, engine running (KOER) self-test. The resulting DTCs are also hard faults and are known as *KOER on-demand faults*. These DTCs should be tested next through pinpoint testing according to the appropriate flowchart.

Continuous Memory Codes. The third code pulling procedure is to pull memory codes from the PCM's memory. Known by Ford engineers as *continuous memory fault codes,* these are codes that were recently set in the PCM's memory when the PCM detected one or more problems during a normal drive cycle. On the EEC V system (as explained in Chapter 14), pulling continuous memory fault codes appears as a separate menu item on a scan tool's display and can be selected individually. But on EEC IV systems, continuous memory fault codes appear automatically following the KOEO self-test. That is, these DTCs are the last codes received following any KOEO self-test, and pulling continuous memory codes cannot be done on an EEC IV system without performing a KOEO self-test first. When the KOEO self-test is performed, the continuous memory DTCs received should simply be recorded at that time. Continuous memory DTCs should be tested last through pinpoint testing according to the appropriate flowchart, following testing of both KOEO and KOER hard faults.

Erasing Continuous Memory Codes. The fourth procedure associated with fault codes is for the technician to erase any continuous memory codes from the PCM's memory. (KOEO and KOER on-demand faults do not need to be erased as they are never stored in the PCM's memory.) The method to delete these codes is to properly perform the repair, then rerun the self-test to verify that the faults are no longer present.

EEC IV Engine System Performance Code Pulling Procedures

Performing a KOEO Self-Test and Pulling Continuous Memory Codes. To initiate a KOEO self-test, the engine should be properly warmed up (if possible), and then the ignition should be turned off for at least 10 seconds. Ford's reasoning behind this is that if any form of self-test has been initiated since the last time the ignition was turned on and the PCM was powered up, another attempt to trigger a self-test will not succeed, but instead will cause the PCM to enter a functional test known as *Continuous Monitor Mode.* Because applications that use a motor to control idle speed (feedback carburetors and central fuel injection [CFI]) must keep the PCM alive after the ignition is turned off for about 8 seconds, this 10-second shutdown rule should be followed. On EFI (port injected) applications, because a duty-cycle solenoid is used to control idle speed, the PCM powers down immediately when the ignition is turned off.

Once the engine has been warmed up and the PCM has been powered down, turn the ignition to the run position. Then jumper from SIG RTN (DLC terminal 2) to STI to trigger the KOEO self-test. The PCM will then perform a self-test, energizing and de-energizing each of the outputs that it controls while checking voltage drop in each circuit. Technician interaction is not required during the KOEO self-test, except on manual transmission 2.5-L and 4.9-L engines, on which the clutch pedal must be held fully depressed during the self-test or false codes will be generated. Also, all accessories should be turned off. If the A/C is turned on during the KOEO self-test, a false code is generated. DTCs will follow. The first codes received are the fast codes (which are unreadable unless a scan tool is being used), followed by the slow codes. The pulsing of the slow codes begins with the KOEO on-demand DTCs and ends with the continuous memory DTCs. In order for the technician to distinguish between the KOEO on-demand DTCs and the continuous memory DTCs, a code 10 is used as a separator (Figure 13–66). Although this appears as a DTC 10 on a scan tool, if slow codes are being counted, it is represented by a single pulse due to the fact that the zero will not trigger any pulses. As a result, Ford writes any code numbers that contain zeroes with the zero in parentheses to show that the zero will not display during slow code output. The fault codes are displayed as a two-digit code on earlier models, with codes 11 through 98 being available. Ford introduced three-digit codes in 1991, with codes 111 through 998 being available. Unlike many other manufacturers, Ford has a DTC that means "system pass." (Other manufacturers, such as GM or Chrysler, use the

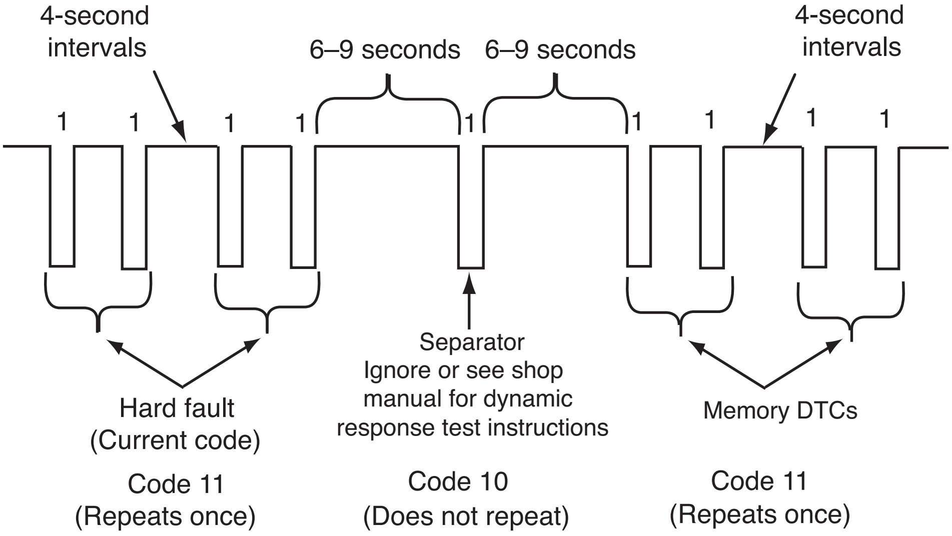

4-second intervals
6–9 seconds
6–9 seconds
4-second intervals
1
1
1
1
1
1
1
1
1
Hard fault (Current code)
Separator Ignore or see shop manual for dynamic response test instructions
Memory DTCs
Code 11 (Repeats once)
Code 10 (Does not repeat)
Code 11 (Repeats once)

Figure 13–66 Key on, engine off, and continuous memory code format.

"absence of DTCs" between anticipated codes to mean "system pass.") This system pass code is DTC 11 in the two-digit code system and DTC 111 in the three-digit code system. Code 11 or 111 will either be received or one or more failure codes will be received; code 11 or 111 will never be received with a failure code within any of the three diagnostic areas. That is, whereas you could get a system pass code in the KOEO self-test area and failure codes in both the KOER self-test and continuous memory areas, you could not get both a system pass code and a failure code in the KOEO self-test area at the same time. This also holds true for the KOER self-test and for the continuous memory.

Following a KOEO self-test, the first codes displayed are the KOEO on-demand faults, either a system pass code or one or more fault codes. When the cycle is complete, each code repeats one more time. Then the separator code 1(0) displays (a single pulse). It does not repeat. Then the continuous memory codes display—again, either a system pass code or one or more fault codes. They, too, repeat one more time. At that point code output ends. At this time, any KOEO on-demand DTCs should be pinpoint tested and repaired, and any continuous memory DTCs should be written down for future reference. The KOEO on-demand codes must display a system pass (code 11 or 111) before a KOER self-test can be performed successfully.

Performing a KOER Self-Test. To perform the KOER self-test, the engine must be fully warmed up and running with the upper radiator hose hot and pressurized. Then, before initiating the self-test, run the engine at 2000 RPM for 2 minutes to ensure that the oxygen sensor(s) are hot and ready for testing. Then let the engine return to idle, turn off the ignition for 10 seconds, restart the engine, and trigger the KOER self-test by placing a jumper wire between SIG RTN and STI. (Or, to avoid fumbling the jumper connection, which would then prevent the self-test from beginning, the jumper between SIG RTN and STI may be made first with the ignition still turned off, then starting the engine.) The PCM will now perform functional tests of many of its sensors, actuators, and controlled systems. For example, the PCM will test the oxygen sensor's output and then use the oxygen sensor(s) to help it perform a functional test of the Thermactor system, directing air flow to the atmosphere and then to the exhaust manifold using the TAB valve (discussed previously in this chapter); it will then direct air downstream to the catalytic converter and then back to the exhaust manifold using the TAD valve. The PCM will also test its ability to increase engine RPM through the idle speed control actuator.

The KOER self-test requires technician interaction. As soon as the technician triggers the KOER self-test, a cylinder ID code is generated (Figure 13–67). This code serves three purposes: It allows the technician to know that the engine performance KOER self-test has been correctly initiated, it tells the technician how many cylinders the PCM is designed for, and it is the technician's cue to interact with the PCM by helping it test up to four different circuits that contain switches.

The cylinder ID code 2(0) indicates a four-cylinder PCM, code 3(0) indicates a six-cylinder PCM, and code 4(0) indicates an eight-cylinder PCM. As soon as the cylinder ID code displays, the technician must push the brake pedal to allow the PCM to test the BOO switch, then quickly turn the steering wheel one-half turn and back to center steer to allow the PCM to test the power steering pressure switch (PSPS). If they exist on the particular vehicle, the technician must also turn on, then turn off the Overdrive Cancel Switch (OCS) and then operate the four-wheel-drive switch to 4 × 4 High and back to two-wheel drive. (These circuits may be tested in any order, however.) Then the PCM continues to test the system while the technician relaxes for a few moments. About the same time that the engine RPM is reduced back to idle, some PCMs will display a code 1(0). This is the technician's cue to interact with the PCM one more time by quickly snapping the throttle to WOT and back. This allows the PCM to test the response of the knock sensor (KS) and the MAP sensor. Ford refers to this as a

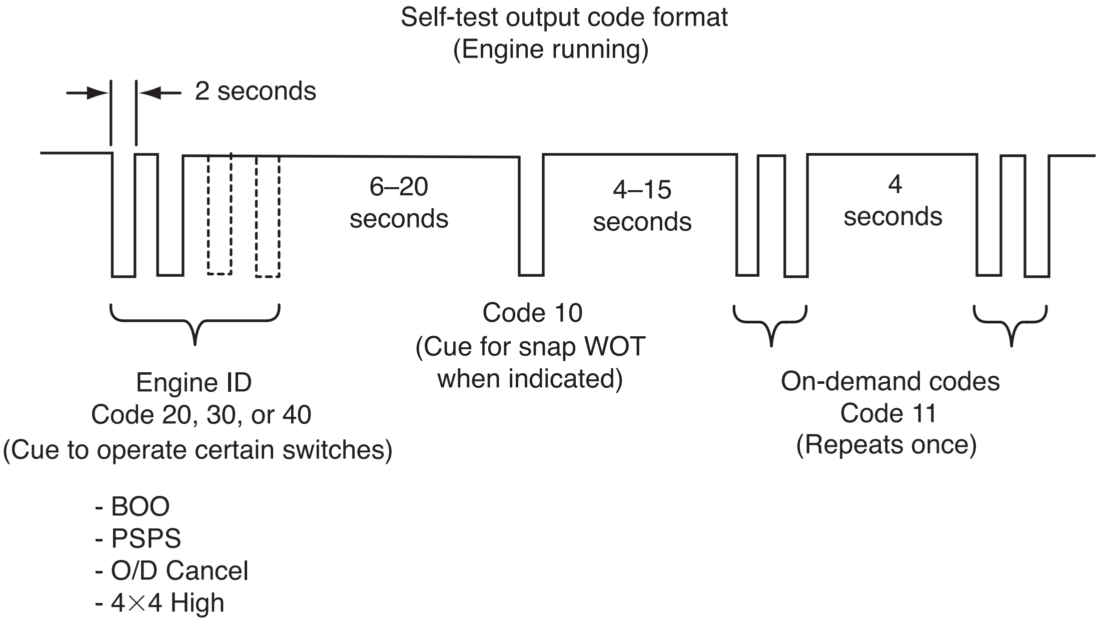


Figure 13–67 Typical service code display during engine running segment of self-test.

Dynamic Response test. (Thus, a code 1(0) during a KOER self-test has a very different meaning from the separator code 1(0) displayed during a KOEO self-test.) Finally, whether the PCM requests a dynamic response or not, fault code output will follow, first displaying the fast codes (unreadable except by a scan tool), then the slow codes. These codes consist of either a system pass code 11 or 111, or one or more fault codes. Any displayed codes repeat one time.

Any DTCs displayed within any of the three areas are displayed by the PCM in the order that they should be repaired.

Erasing Continuous Memory Codes. Finally, to erase memory codes from the PCM's memory, a KOEO self-test should be initiated. As soon as the fast codes (or first slow codes) display, the test should be prematurely aborted by disconnecting the jumper wire between SIG RTN and STI prior to completion of the code output. This action instructs the PCM to erase all continuous memory DTCs. If erasing of continuous memory codes is selected on a scan tool's menu, the scan tool will do this internally.

EEC IV Engine System Performance Functional Tests

There are four functional tests, or diagnostic aids, programmed into an EEC IV PCM. For most (though not all) functional tests, the PCM does not determine the pass/fail status of a component/circuit, nor does it generate DTCs (the exception to this is Ford's cylinder power balance test). Rather, it is up to the technician to determine pass/fail status of the circuit or component, using the functional test as an aid in making that determination. The technician may be directed to a particular functional test by a flowchart or may choose to use a functional test without the service manual's direction.

Computed Timing Check. This functional test checks the ability of the PCM to properly control computed ignition timing. But first, base

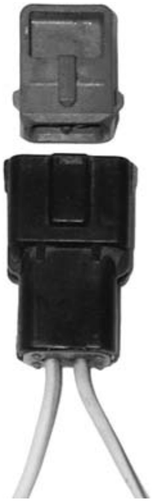


Figure 13–68 SPOUT connector with shorting bar, 1986 and newer.

timing must be verified as correct and readjusted if necessary. To do this, the SPOUT circuit must be opened electrically by disconnecting the male/female connector near the distributor (1983 to 1985 models) or pulling the shorting bar in the SPOUT circuit (Figure 13–68) (1986 to 1996 models).

Once the base timing is verified, reinstall the SPOUT connector. Then perform a KOER self-test. Following the last code output, wait 10 seconds to verify that the last code has been received. The PCM will now add 20 degrees of spark advance to base timing for 2 minutes following the completion of the KOER self-test or until the self-test is deactivated, whichever occurs first. The specification is base timing plus 20 degrees with a tolerance of ±3 degrees. That is, if base timing was verified at 10 degrees BTDC, then timing advance during the computed timing check should be between 27 degrees and 33 degrees BTDC. (This is the only time that the technician can place a specification on computed timing.)

Continuous Monitor Mode (Wiggle Test). This functional test aids the technician in identifying intermittent faults within the EEC IV system, particularly with the sensor circuits. For this test to work, there must be no hard faults present within these circuits. To initiate this test, run either a KOEO or KOER self-test (depending upon which state you need the engine in during this functional test), and then, after the last code is output, wait 10 seconds. At this point, deactivate and reactivate the self-test by disconnecting and reconnecting the jumper wire between SIG RTN and STI. (The scan tool will do this internally when this functional test is selected.) The test is now active and will alert the technician to any sensed fault. Tap on the component in question, wiggle its connector, and wiggle the harness all the way from the component to the PCM while watching for the analog voltmeter's swing needle to go to battery voltage or for the scan tool's LED to illuminate.

Output State Check. This functional test allows the technician to command the PCM to energize and de-energize several actuators, particularly those associated with emission systems. This allows the technician to test the ability of the PCM to energize these actuators and also allows the technician to perform other tests (such as vacuum tests associated with vacuum solenoids) while this mode is active. To initiate this test, perform a KOEO self-test, wait for the final code output, and then wait 10 seconds. (Do not deactivate the self-test.) Now move the throttle to WOT and back to idle to energize these actuators. Move it to WOT and back to idle again to de-energize these actuators. This action may be repeated as needed.

SEFI Cylinder Balance Test. This functional test provides an easier method for the technician to perform a power balance test than using an ignition scope, but it applies only to sequentially fuel-injected EEC IV systems from 1985 through 1995. The PCM uses each fuel injector in turn to disable fuel delivery to each of the cylinders as it measures RPM drop. It also automatically stabilizes ignition timing, engine RPM, and electric cooling fan operation prior to beginning the test. At the end of the test, the PCM compares cylinder readings and reports the results to the technician through code output.

Test Level			*DTC 9(0)* = "*System Pass*"
One (spec = 65%)	Two (spec = 43%)	Three (spec = 20%)	
DTC	***DTC***	***DTC***	***Indication***
9(0)	(not needed)	(not needed)	All cylinders passed
5(0)	9(0)	(not needed)	Cyl. #5 is slightly weak
5(0)	5(0)	9(0)	Cyl. #5 is moderately weak
5(0)	5(0)	5(0)	Cyl. #5 is dead/nearly dead

Figure 13–69 SEFI cylinder balance test.

To initiate this test, perform a KOER self-test. (Of course, the engine should be fully warm.) After the last code is output, wait 10 seconds, and then slightly tip in the throttle and release. The slight change in TPS voltage instructs the PCM to enter the cylinder balance test. After raising and stabilizing engine RPM, the PCM begins dropping the cylinders, one at a time, beginning with the highest numbered cylinder. Then it reduces engine RPM back to idle and report the results. DTC 9(0) indicates that all cylinders passed. DTCs 1(0) through 8(0) indicate failures in cylinders 1 through 8, respectively. The 1986 and newer models can run this test to each of three different failure specification levels (Figure 13–69).

If, after the first test, a DTC 9(0) is received, indicating that all cylinders passed, there is no need to initiate further levels of the test. But if a failure code is received—DTC 5(0), for example, indicating that cylinder 5 failed the test—then simply, once again, slightly tip in and release the throttle to initiate the next level of the test. If a DTC 9(0) is received at this point, cylinder 5 is slightly weak and simply failed to drop at least 65 percent of the RPM drop recorded on the strongest cylinder. But if at the end of the second test a DTC 5(0) is still received, then slightly tip in the throttle and release it one more time to initiate the final test. If DTC 9(0) is again received, cylinder 5 did not drop at least 43 percent of the RPM drop recorded on the strongest cylinder and is perceived as being moderately weak. If, however, at the end of the final test, DTC 5(0) is still received, cylinder 5 did not drop even 20 percent of the RPM drop recorded on the strongest cylinder and is perceived as a dead or nearly dead cylinder. Any further tests initiated beyond this point will use the 20 percent specification level. A DTC 77 indicates that the test should be restarted. This test quickly isolates a weak cylinder and indicates the level of failure, but it is still up to the technician to determine the cause of the failure, whether it is mechanical, ignition, or fuel related.

EEC IV Engine System Performance Quick Test

When directed to by the *H Manual*'s Diagnostic Routines section, the technician should perform a **Quick Test,** as defined in the *H Manual*. The Quick Test is a seven-step procedure, as follows:

Step 1: Visual check, vehicle preparation
Step 2: Equipment hookup (either scan tool or manual method)
Step 3: KOEO self-test
Step 4: Computed timing check
Step 5: KOER self-test
Step 6: Continuous memory code diagnosis (retrieved during the KOEO self-test)
Step 7: Diagnosis by symptom

The Quick Test thus includes these seven items that Ford engineers consider of equal importance. Ultimately, steps 3 through 7 can direct the technician to an appropriate flowchart for diagnosis. (Ford's defined Quick Test does not simply equate to a self-test, but, rather, includes both self-tests and other diagnostic aids.)

EEC IV IVSC (Speed Control) System Performance Code Pulling Procedures

On those EEC IV vehicles that have IVSC, the PCM does not store speed-control–related DTCs in memory as it does with engine performance DTCs. However, it will perform both KOEO and KOER self-tests relating to the speed control function. DTC output from the PCM may still be read in the methods previously described, or a scan tool may also be used.

Performing an IVSC KOEO Self-Test. To initiate an IVSC KOEO self-test, simply turn on the ignition, and then trigger the self-test by depressing the speed control *On* switch. (The jumper wire between SIG RTN and STI is not used to trigger this test as it was for both of the engine performance tests. Rather, depressing the *On* switch is recognized by the PCM as the trigger as long as the engine is not running.) A code 1(0) should be received immediately, indicating that the IVSC self-test has been entered. Then, within 15 seconds, depress *Off, Resume, Set/Accel,* and *Coast.* Also depress both the brake and clutch pedals. (Do not touch the throttle.) Code output will follow, first the fast codes and then the slow codes. Again, DTC 11 indicates a system pass. (This system was discontinued the year that Ford introduced the three-digit code system.)

Performing an IVSC KOER Self-Test. To initiate an IVSC KOER self-test, the engine must be fully warm and running, then a double trigger is used to trigger the self-test. First, depress the speed control on switch. Then, within 15 seconds, use a jumper wire to connect SIG RTN to STI. If this is successful, the PCM will immediately respond with a DTC 1(0), indicating that the IVSC KOER self-test has been entered. No technician interaction is required during this self-test. The PCM will test its ability to increase engine RPM using the speed control servo (rather than the ISC actuator, as with the engine performance KOER self-test). After the engine slows down, code output will follow, first the fast codes and then the slow codes. Again, DTC 11 indicates a system pass.

EEC IV Data Stream

In 1989, Ford added a data stream capability to its California models. In 1991, this was added to its federal models. This simply added the ability for a scan tool to read data stream values, including sensor values and actuator commands; it is similar to GM's data stream.

EEC IV Breakout Box

An EEC IV breakout box may be installed to aid in pinpoint testing the various circuits/components. Many flowcharts call for the technician to connect a breakout box. If resistance checks are to be performed, or if actuators are to be energized manually from the breakout box, the PCM is left disconnected. That is, the breakout box should be connected to the EEC IV electrical harness only. The PCM should be connected to the breakout box if the system needs to be operational and if voltage, frequency, duty cycle, or pulse-width checks are to be made.

Pinpoint Testing

Ultimately the goal of any diagnostic approach is to correctly identify and repair the problem. To this end, the *H Manual* contains pinpoint test charts or flowcharts that the technician can be directed to by any of the engine performance or IVSC self-tests, by a Continuous Memory DTC, by a failure of the Computed Timing Test, or by a symptom. Many aftermarket service manuals utilize a combination flowchart, using the letter O to refer to DTCs generated by a KOEO self-test, the letter R to refer to DTCs generated by a KOER self-test, and the letter C to refer to Continuous Memory DTCs.

Failure Mode Effects Management. Failure Mode Effects Management (FMEM) is a strategy programmed into the PCM, beginning in mid-1986, to maintain a good engine performance in the event that one of the most critical sensors fails. Prior to 1987, such a sensor failure would either stop the engine or put the system into *limited operational strategy* (in which the engine runs with no spark advance and a fixed air/fuel mixture). With FMEM Strategy, the PCM will, in most cases, be able to replace the failed sensor's input with a plausible substitute value based on another sensor. It will also set a code 98 in its continuous self-test memory. Code 98, in 1987, indicates that a fault exists and that FMEM is functional.

The operator may not know a fault exists except for the following:

- Idle speed may be fixed.
- The cooling fan may run all the time.
- The MIL on the instrument panel will illuminate when the fault occurs (1988 and newer vehicles).

All 1987 and later EEC IV vehicles employ FMEM Strategy. Figure 13–70 shows the sensors included in the FMEM Strategy and the action taken in response to each one's failure.

Failed Sensor	Action Taken
MAP	Substitute TPS value. If TPS is faulty, use a fixed constant value. Disable Adaptive Learning. Disable EGR. Fixed idle speed.
TPS	Substitute fixed values during cranking, MAP value after engine starts.
ECT	Substitute IAT value during warm-up, fixed value after warm-up. Disable EGR. Disable Adaptive Learning. Fixed idle speed.
IAT	Substitute ECT value during warm-up, fixed value after warm-up. Disable EGR. Disable Adaptive Learning. Fixed idle speed.
EVP	No substitute. Disable EGR.

Figure 13–70 FMEM strategy.

Self-Test Improvements. Several improvements have been made in the self-test over the years. Some new codes have been added and some codes have been made more reliable. The self-test and the continuous monitor have the capacity to check more functions. Consequently, code numbers may change meaning from year to year. The technician must have current published information for the vehicle being worked on.

Adaptive Strategy and Driveability. If for any reason the continuous battery power to the PCM is interrupted for more than 3 minutes, the adaptive strategy learning is erased. The calibration values stored in the KAM revert to the original look-up table values in the read-only memory. Because the learned values compensated for some engine wear or component inefficiency, the vehicle may have driveability problems such as surging, hesitation, or poor idle until the PCM can relearn.

A parallel problem—one not always understood by inexperienced technicians—is that if a component that is replaced was one the adaptive strategy had compensated for, the vehicle might have driveability problems with the new, fully functional component until the PCM has an opportunity to learn the characteristics of the new or repaired part. To avoid this problem after replacement or repair of significant system components, interrupt battery power to the KAM for at least 3 minutes during or after such a repair. This is particularly important for major engine component replacements.

MAP/BP Relocation. Beginning in 1987, MAP and/or BP sensors were repositioned so they sit in a horizontal position with the vacuum line sloping downward to its manifold connection. This prevents fuel migration into the sensor. Fuel getting into these sensors has been responsible for many pressure sensor failures.

Diagnostic & Service Tips

Here are a few final suggestions when working on Ford vehicles with an EEC IV system:

- Pinpoint procedures should not be used unless the Quick Test directs you to do so. Each pinpoint procedure assumes a fault has been detected in the circuit being considered. To use them without being directed by the Quick Test can result in unnecessary and thus ineffective repairs and the replacement of functional parts. Do not replace parts unless specific test procedures indicate they are defective.
- Do not connect a test light at the PCM harness connector unless specifically directed to do so by a particular test procedure. Otherwise, damage to the PCM or to sensors or actuators could result.
- Isolate both ends of a circuit and turn the ignition off before testing for shorts or continuity unless otherwise directed by a specific test procedure. This same rule applies to solenoids and switches. All circuit resistance tests must be made with the circuit electrically separated from the rest of the system, unless you are using voltage-drop techniques.
- An open circuit is any resistance greater than 10,000 Ω, and a good connection is any path with less than 5 Ω, unless otherwise specified.

SUMMARY

In this chapter, we have covered the three operational strategies of the EEC IV system. We have reviewed the major sensors: for engine coolant temperature (ECT), engine speed, throttle position, manifold pressure, and residual oxygen in the exhaust. We have seen the ignition system unique to Ford, with the SPOUT and PIP signals. We saw how they work and what their input information signals to the PCM look like.

We have reviewed the CFI, EFI, and SEFI fuel management systems that are found on EEC IV systems and have looked at the specific characteristics of each system. We saw which components most directly affect emissions and which are more concerned with driveability or fuel economy. Finally, we looked at the major aspects of the diagnostics and repair of the EEC IV system.

▲ DIAGNOSTIC EXERCISE

An EEC IV vehicle with a SEFI system comes into the shop because it failed an emissions test for high CO (rich air/fuel mixture), but it seems to perform okay. The technician discovers that the fuel pressure regulator will not hold vacuum due to a small tear in the diaphragm and is apparently leaking unmetered fuel into the intake manifold through the vacuum hose. After getting the owner's approval, a new pressure regulator is installed. After the engine is started, it appears to have developed a lean surge and actually runs worse than before the pressure regulator was replaced. What is the most likely problem, and what should be done to correct it?

Review Questions

1. Technician A says that an EEC IV PCM uses its keep-alive memory (KAM) to store fault codes related to faults that occurred but are no longer present. Technician B says that in

an EEC IV system the engine calibration assembly is an integral part of the PCM that is soldered into it, and it cannot be removed or serviced separately. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

2. What is the ability of the EEC IV PCM to learn to compensate for variations in manufacturing tolerances, wear, or deterioration of sensors and other components called?
   A. Base engine strategy
   B. Modulator strategy
   C. Limited operational strategy
   D. Adaptive strategy
3. Which of the following sensors in an EEC IV system requires a frequency meter to interpret its signal to the PCM?
   A. ECT
   B. MAP
   C. TPS
   D. EVP
4. What is the name of the signal generated by the Hall effect sensor in an EEC IV distributor?
   A. PIP
   B. SPOUT
   C. IDM
   D. CID
5. What is the name of the signal used in an EEC IV system to allow the PCM to verify that the spark timing command was carried out and to verify whether the calculated spark timing advance is working properly?
   A. PIP
   B. SPOUT
   C. IDM
   D. CID
6. What is the name of the signal used in an EEC IV system to allow the DIS ignition module to know which ignition coil to fire?
   A. PIP
   B. SPOUT
   C. IDM
   D. CID
7. Which of the following sensors monitors EGR flow rate?
   A. IAT
   B. EVP
   C. PFE
   D. VAF
8. All except which of the following inputs are switches?
   A. ITS
   B. VAT
   C. BOO
   D. PSPS
9. Technician A says that the VSS generates DC voltage signals. Technician B says that the VSS generates 64,000 pulses per mile at 60 MPH and will generate fewer pulses per mile at slower speeds. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
10. Technician A says that some Ford pickup trucks and vans use multiple fuel pumps, a low-pressure "lift pump" mounted in the fuel tank, and a high-pressure in-line pump. Technician B says that Ford low-pressure CFI systems are regulated to 14.5 PSI and use a single fuel injector. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
11. A fuel-injected Ford vehicle will crank but not start. The technician verifies that the fuel pump does not run when the ignition is turned on. What is the next thing that the technician should do?
    A. Replace the PCM.
    B. Follow the flowchart for diagnosing the fuel pump relay.
    C. Remove the fuel pump from the fuel tank for testing.
    D. Check the inertia switch.
12. Technician A says that the SPOUT signal is an analog voltage signal. Technician B says that the SPOUT signal is used by the PCM to

command the TFI-IV ignition module to fire the ignition coil. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

13. Technician A says that on the Thermactor system, the TAB valve is under the control of the PCM-controlled TAB solenoid and is used to direct air flow to the TAD valve or to atmosphere. Technician B says that on the Thermactor system, the TAD valve is under the control of the PCM-controlled TAD solenoid and is used to direct air flow upstream to the exhaust manifold or downstream to the catalytic converter. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

14. On an EEC IV system, continuous memory codes occur automatically after performing which of the following?
   A. KOEO self-test
   B. KOER self-test
   C. Computed timing check
   D. SEFI cylinder balance test

15. What is the purpose of connecting an analog voltmeter between battery positive and STO during diagnostics?
   A. To initiate the KOEO and KOER self-tests
   B. To read code output
   C. To perform a voltage-drop test on the positive side of the PCM
   D. To read base ignition timing

16. Technician A says that when diagnosing an EEC IV engine performance symptom, the KOEO self-test must indicate a system pass before a KOER self-test can be performed successfully. Technician B says that the engine performance KOER self-test requires technician interaction in order to be performed properly. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

17. EEC IV DTCs consist of which of the following?
   A. Single-digit codes
   B. Two-digit codes
   C. Three-digit codes
   D. Either two-digit or three-digit codes depending on the year and model

18. Initiating a KOEO self-test and aborting it prematurely (after code output begins but before it completes) is a method of instructing an EEC IV PCM to do which of the following?
   A. Erase KOEO on-demand fault codes
   B. Erase KOER on-demand fault codes
   C. Erase continuous memory fault codes
   D. All of the above

19. During an SEFI cylinder balance test, an EEC IV PCM does which of the following?
   A. Stabilizes engine RPM, ignition timing, and cooling fan operation
   B. Turns off one fuel injector at a time and measures RPM drop
   C. Compares the cylinders against the strongest cylinder
   D. All of the above

20. Technician A says that FMEM is a strategy programmed into an EEC IV PCM to maintain good engine performance in case one of the most critical sensors was to fail. Technician B says that FMEM is an EEC IV strategy that will use another sensor to substitute a good value for a failed sensor. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

Chapter 14

Ford's Electronic Engine Control V (EEC V)

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Describe the major aspects of the EEC V PCM.
- ☐ Define the inputs used with the EEC V system.
- ☐ Understand the differences between the return-type fuel injection system and the electronic returnless fuel injection system.
- ☐ Describe the various types of ignition systems used with the EEC V system, including both types of distributorless systems.
- ☐ Define the emissions systems used with the EEC V system.
- ☐ Understand how Ford's new DPFE sensor works differently from the traditional one.
- ☐ Describe some of the advanced features that are used in conjunction with EEC V systems, including Variable Cam Timing, Electronic Throttle Control, Intake Manifold Runner Control, Fail-Safe Cooling, Adaptive Cruise Control, Ford's voice recognition and navigational system, and Ford's AdvanceTrac™ system.
- ☐ Define the differences between Ford's GEM, REM, and FEM electronic control modules.
- ☐ Comprehend what is meant by the term *intelligent architecture.*
- ☐ Understand the basic design of the fire suppression system that was recently introduced on the Ford Crown Victoria Police Interceptor (CVPI).

KEY TERMS

Adaptive Cruise Control
AdvanceTrac™
Alternate Fuel Compatibility
Conversational Speech Interface Technology
Fail-Safe Cooling
Front Electronic Module (FEM)
Generic Electronic Module (GEM)
Intake Manifold Runner Control (IMRC)
Intelligent Architecture
Rear Electronic Module (REM)
Throttle Plate Position Controller (TPPC)
Variable Cam Timing (VCT)

Ford Motor Company took a unique approach to meeting OBD II standards. Rather than modifying an existing system to meet OBD II standards (as most other manufacturers did), they designed a new engine computer system, known as Electronic Engine Control V (EEC V), with OBD II specifically in mind. The EEC V system carries over from EEC IV many of the features with which you are already familiar (see Chapter 13), and adds several other features under OBD II standards in order to improve a technician's diagnostic effectiveness (see Chapter 8).

ENGINE CONTROLS

Powertrain Control Module

Initially, the EEC V powertrain control module (PCM) made its debut as a 104-pin processor (Figure 14–1) (compared to an EEC IV processor, which contained only 60 pins). By making each of the pins (terminals) smaller in size and arranging them closer together in four rows, Ford engineers actually were able to design the 104-pin connector to be physically no larger than the EEC IV connector had been. The PCM controls fuel delivery and ignition timing throughout the range of the engine's operational capacity. It monitors the various sensors and switches whose information is relevant to calculating the proper values for fuel injector pulse widths and firing sequence, as well as to triggering actuation of the various components that execute its combustion commands.

The EEC V PCM determines the gradual wearing and aging of the vehicle over time, as well as changes in altitude or barometric pressure; it can then make compensatory adjustments in its own programs to make whatever changes are needed due to the changing input values.

The principal inputs to the PCM are the throttle position sensor (TPS), the mass air flow (MAF) sensor, the intake air temperature (IAT) sensor, the engine coolant temperature (ECT) sensor, the oxygen sensor, the camshaft position (CMP) sensor, the knock sensor (KS), the power steering pressure (PSP) switch, and the vehicle speed sensor (VSS).

INPUTS

Throttle Position Sensor

On the side of the throttle body is a variable potentiometer that provides a return signal to the PCM directly proportional to the position of the throttle plate (Figure 14–2). This works the same way TP sensors have since 1981, and the potentiometer sweep tests are still quite similar—you check for continuous variation in the resistance and return voltage throughout the throttle travel from idle to WOT.

Mass Air Flow Sensor

The Ford EEC V system uses a hot-wire-type MAF sensor (Figure 14–3). The hot wire in the air stream is kept at a constant temperature above the ambient air, and a hot-wire-sensing element measures exactly how much current is required to maintain that heat. The sensor sends an analog voltage signal to the PCM corresponding to the mass of the intake air. Of course, as with all such air mass sensors, it is very important to make sure there are no downstream air leaks, as any intake air that does not go through the sensor will result in a false signal to the computer.

Intake Air Temperature Sensor

This sensor (Figure 14–4) is an NTC thermistor that varies its resistance in response to the temperature of the intake air charge. As the IAT rises, the resistance of the IAT sensor decreases,

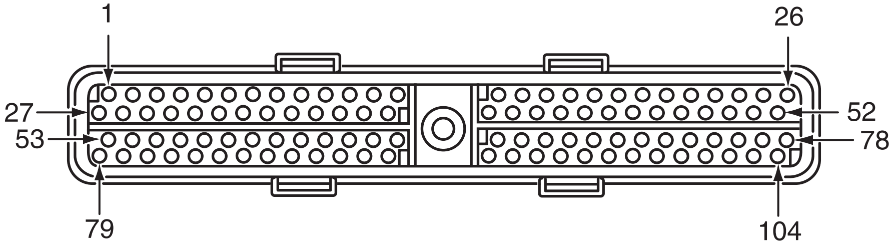


Figure 14–1 EEC V PCM 104-pin harness connector.

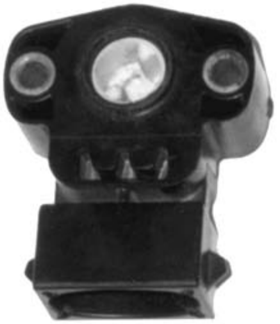


Figure 14–2 Throttle position sensor.

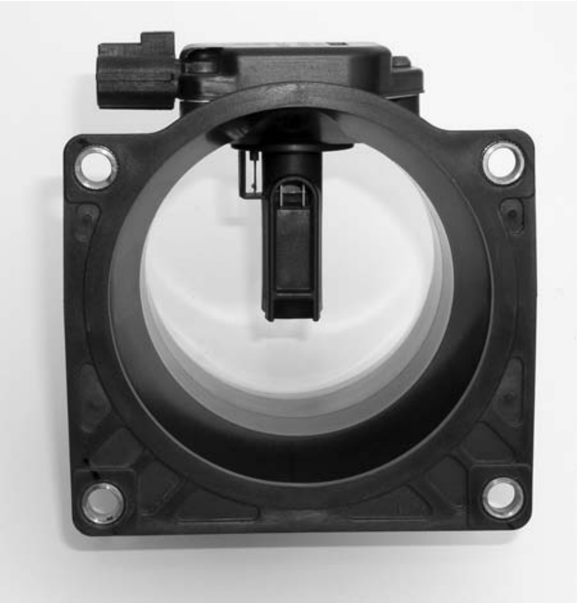


Figure 14–3 MAF sensor.

causing the voltage drop measurement across the sensor to decrease proportionately.

Engine Coolant Temperature Sensor

Like the IAT sensor, the ECT is a variable resistance thermistor. It changes its resistance in response to ECT. It is similar to the IAT sensor in Figure 14–4 except that the thermistor is enclosed and therefore sealed from the engine's coolant.

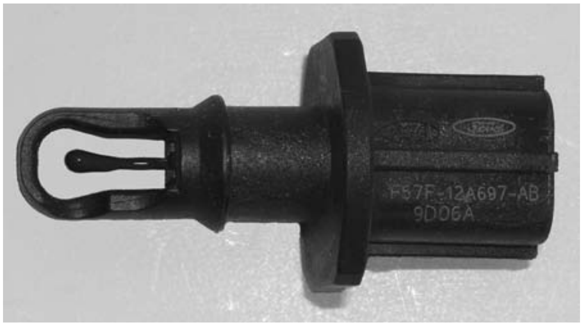
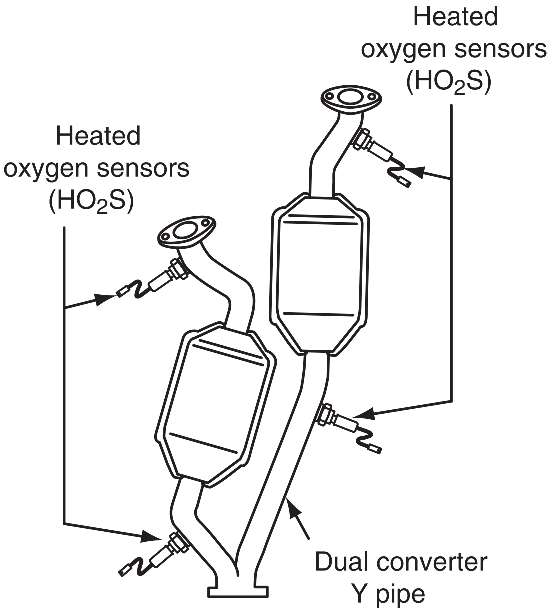


Figure 14–4 IAT sensor.

Heated Oxygen Sensors (HO_2S)

The oxygen sensor system is different from earlier computer control systems chiefly in that there are four of them. Two are placed before the catalytic converters and are used for closed-loop control of the air/fuel ratio, and two are placed after the catalytic converters to monitor the effectiveness of the catalytic converters (Figure 14–5). All four are electrically heated to reach operating temperature as quickly as possible. The downstream, secondary sensors should have



Heated oxygen sensors (HO_2S)
Heated oxygen sensors (HO_2S)
Dual converter Y pipe

Figure 14–5 Heated oxygen sensors.

a relatively flat signal if the catalytic converter is operating efficiently. If the secondary oxygen sensors' signal is a reflection of the primary sensors' signal, the catalytic converter has lost its effectiveness at converting the exhaust gasses. It is recommended, however, because only a small inefficiency can result in a DTC for catalytic converter inefficiency, that the technician not attempt to use the waveform of the downstream oxygen sensors as a diagnostic tool. If an efficiency DTC has been set for a catalytic converter, verify that there are no DTCs set for the oxygen sensors themselves and that there are no exhaust leaks ahead of the cats. Use a scan tool to check fuel trim values. Also, check for technical service bulletins (TSBs). Otherwise, believe the DTC and replace the catalytic converter identified by the DTC.

Vehicle Speed Sensor

The Ford VSS uses a magnetic pick-up to send a rapid on/off pulse, the frequency of which corresponds to the vehicle's speed. The PCM uses this information, among other things, to calculate fuel mixture and ignition timing. Since the new transaxles are also, in large measure, electronically controlled, the VSS signal plays a role in that function.

Knock Sensor

The KS (Figure 14–6), is the usual piezoelectric crystal type, which produces an AC voltage signal in response to the occurrence of detonation. This information is used by the PCM to retard spark advance so as to eliminate the spark knock.

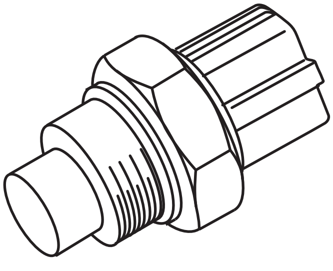


Figure 14–6 Knock sensor.

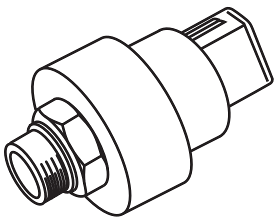


Figure 14–7 PSP switch.

Power Steering Pressure Switch

The PSP switch (Figure 14–7) is installed in the boost side of the power steering pump. Electrically, it is normally closed. When hydraulic boost builds to the point where it could be a load on the engine, the switch opens. This provides the computer with information relevant to setting the idle speed.

Camshaft Position Sensor

On the two-valve-per-cylinder engine, the CMP sensor is a single Hall effect magnetic switch activated by a vane driven by the camshaft. On the four-valve-per-cylinder engine, the CMP sensor is a variable reluctance (permanent magnet) sensor triggered by the high point on the left exhaust camshaft sprocket. In both cases, the sensor provides the PCM with information used to synchronize the fuel injection sequence with the cylinder firing order.

Crankshaft Position Sensor

The crankshaft position (CKP) sensor (Figure 14–8) produces the tach reference signal for the ignition system. It consists of a variable reluctance sensor (permanent magnet) and produces an AC voltage signal. It monitors a toothed gear with one tooth spaced every 10 degrees of crankshaft rotation, except for one blank space where a tooth was left out. This is commonly referred to as a "36-minus-1-tooth" arrangement. The tip of the sensor and the toothed gear may be located either inside the timing gear cover, as on the 3.0-L engine, or the sensor may monitor teeth that are located on the harmonic balancer and are then, of course, external of the timing gear cover, as on the 4.0-L engine.

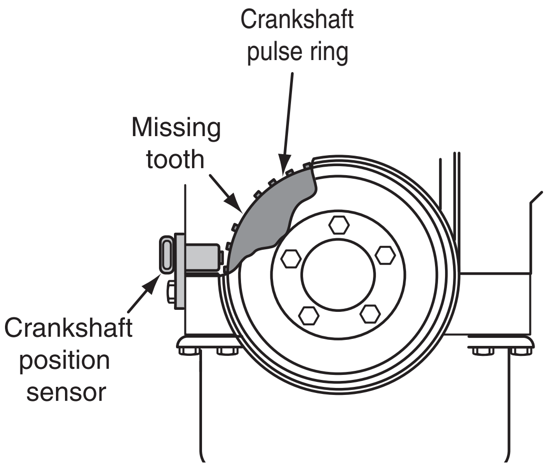


Figure 14–8 CKP sensor.

The missing tooth identifies the position of the crankshaft for the PCM. Then, with the other teeth, the PCM is able to count off crankshaft rotation in 10-degree increments. This arrangement is considered a high-resolution signal, providing enough pulses per cylinder firing to allow the PCM to determine whether a cylinder is misfiring by watching the frequency of the pulses, as specified by OBD II standards. Even on an eight-cylinder engine, the PCM is able to count off nine teeth per cylinder firing (except, of course, for the missing tooth). This signal is used by the electronic distributorless ignition system (EDIS) to identify each pair of pistons as they approach TDC. In the waste spark application, this information allows the PCM to fire the correct ignition coil. In the coil-per-plug (CPP) application, the signal from the CMP sensor is also needed to determine the appropriate ignition coil to fire (as well as to determine which fuel injector to pulse).

OUTPUTS

Return-Type Fuel Injection System

Fuel Pump Relay. As in other systems, when the ignition is first turned to "run," the PCM energizes the fuel pump relay for 2 seconds to run the fuel pump and top off the fuel system's residual pressure. As the starter motor begins cranking the engine, a tach reference signal is sent to the PCM from the CKP sensor, the PCM continues to keep the fuel pump relay energized, and the fuel pump continues to run. If the tach reference signal is lost, the PCM will de-energize the fuel pump relay within 2 seconds. As a result, if a fuel pressure line were to rupture during an accident, resulting in engine stall, the PCM would shut down the fuel pump to avoid the potential for emptying the fuel tank onto the ground through the ruptured line.

Inertia Switch. Like earlier Ford (EEC III and EEC IV) fuel injection systems, the EEC V fuel injection system employs an inertia switch, also called a "fuel pump shutoff switch." This component offers additional protection from gasoline fires in case of a collision. If a collision occurs, the jolt is likely to trip open the inertia switch, which, in turn, electrically removes power from the fuel pump. This is a safety design used in addition to the "loss of the tach reference signal" concept just described. This helps to ensure that fuel from the fuel tank is not spilled onto the ground if a collision were to result in any of the following:

- Fuel pressure lines being loosened enough to leak fuel without causing enough of a pressure loss to stall the engine.
- Simultaneous rupturing of a fuel pressure line along with a shorting to ground of the fuel pump relay control circuit from the PCM, thereby negating the PCM's ability to disable the fuel pump.
- Rupturing of the fuel return line, which would not result in engine stall but could still spill fuel from the fuel tank onto the ground.

Although Ford's inertia switches have been improved over the years, it is still possible to find one that has been tripped due to something less than an accident (for example, due to the vehicle being bumped by another vehicle at slow

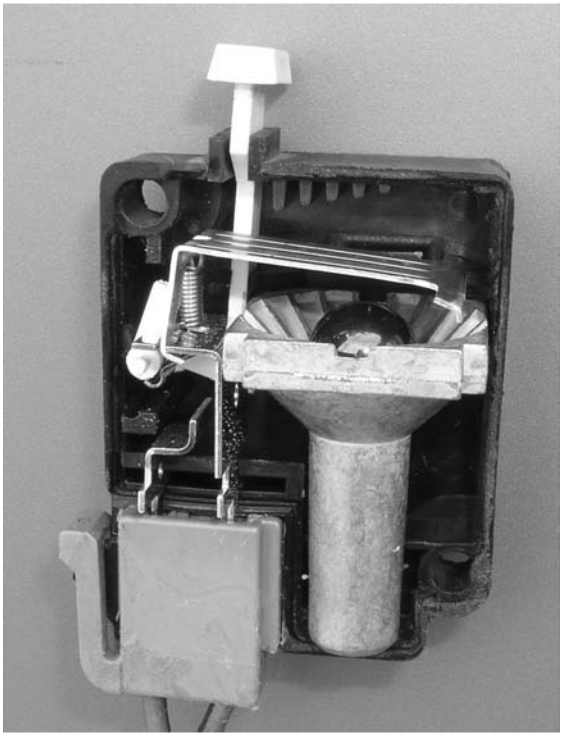


Figure 14–9 Inertia switch components.

speed, as in a parking lot). The inertia switch (Figure 14–9) contains a steel ball (weight) and a cone. The ball is held in place in the center of the cone by a permanent magnet placed beneath it. An impact from any side dislodges the ball, allowing the cone to deflect the ball upward against a target plate, which opens a set of electrical contacts, pushing up a reset button. The inertia switch is mounted on a metal frame of the vehicle. It is located in the trunk on early passenger cars or underneath the instrument panel mounted either on the firewall (Figure 14–10) or behind a kick panel on many newer passenger cars, as well as on most light trucks, minivans, and SUVs. If the inertia switch has tripped, the fuel pump can be re-enabled by depressing the reset switch. Most experienced technicians will check the inertia switch's reset button as part of the initial visual inspection when diagnosing a no-start complaint.

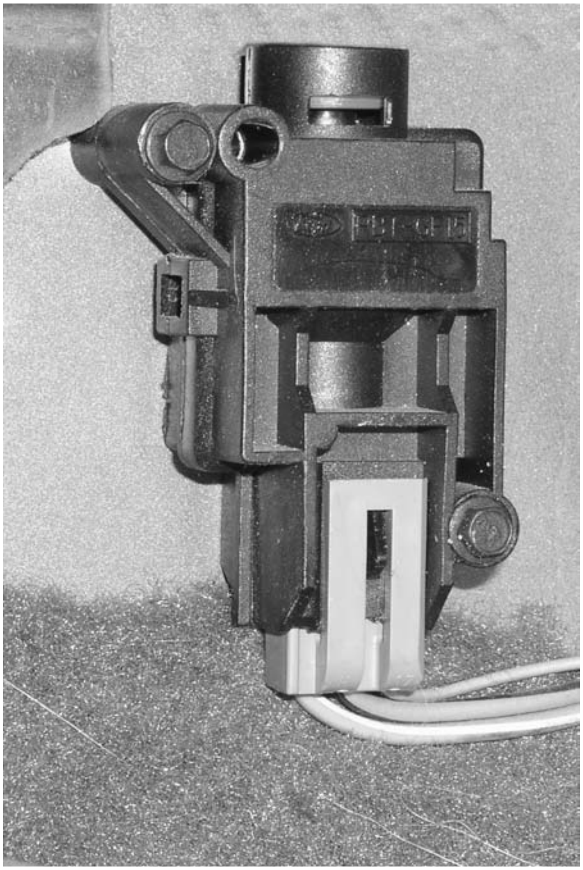


Figure 14–10 Inertia switch mounted to the interior side of the firewall.

CAUTION! When resetting a Ford inertia switch that has tripped, it is critically important for the technician to follow the resetting of the switch by pressurizing the fuel system and then performing a careful visual inspection of the entire fuel system to check for leaks. Failure to do this when resetting a Ford inertia switch can leave the technician liable for damage resulting from any existing fuel leaks.

Fuel Injectors. The fuel injectors used with EEC V are designed with **alternate fuel compatibility,** meaning that they are compatible with both methanol and ethanol, as well as with gasoline. The O-rings that seal them in the manifold are likewise methanol and ethanol compatible, as should be any replacements. These injectors use a pintle designed to resist deposits from fuel additives as well. The PCM grounds each injector's circuit in turn, completing its circuit and opening the nozzle. The injection occurs just prior to the intake stroke in the firing order of the engine.

Fuel Pressure Regulator: Return Type System. The fuel pressure regulator, which is also designed for alternate fuel compatibility, connects to the fuel rail (or fuel injection supply manifold, as Ford literature prefers to describe it) downstream of the injectors (Figure 13–40 in Chapter 13). It regulates the fuel pressure at the injectors through the interaction of its diaphragm-operated relief valve. One side of the diaphragm senses fuel pressure, and the other is subject to manifold pressure (vacuum). The initial fuel pressure is determined by the specially calibrated spring preload. The purpose of the arrangement is to maintain the fuel pressure drop through the fuel injectors at a constant pressure differential, regardless of changes in the intake manifold pressure, and to make it simpler to calculate the fuel injection pulse width. As long as the pressure differential is constant, a fixed amount of fuel will flow for a fixed pulse width. If the pressure differential were allowed to vary, the PCM would have to compensate for different fuel quantities. Pressure is reduced from the pump's maximum outlet pressure by venting enough back to the tank to keep the rail charged at the design pressure.

Electronic Returnless Fuel Injection System

Like to most other manufacturers' systems of the past, the Ford fuel pressure regulator has traditionally been located in the engine compartment on the fuel rail and releases excess fuel into the return line, which then carries it from the engine compartment back to the fuel tank. An unfortunate result of this design has always been that engine compartment heat was carried back into the fuel tank through the return line as well, thereby increasing the tendency of the fuel in the tank to vaporize. Beginning in the 1998 model year, several Ford applications use an electronic returnless fuel system designed to reduce the amount of engine compartment heat that gets carried back to the fuel tank. A fuel pressure sensor is mounted at the fuel rail in the engine compartment (Figure 14–11) and

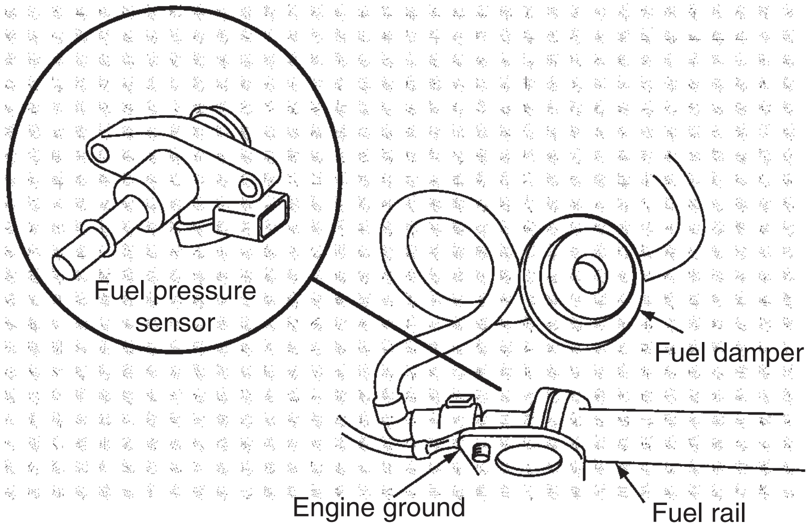


Figure 14–11 This pressure sensor monitors fuel system pressure and intake manifold pressure as an input to the PCM.

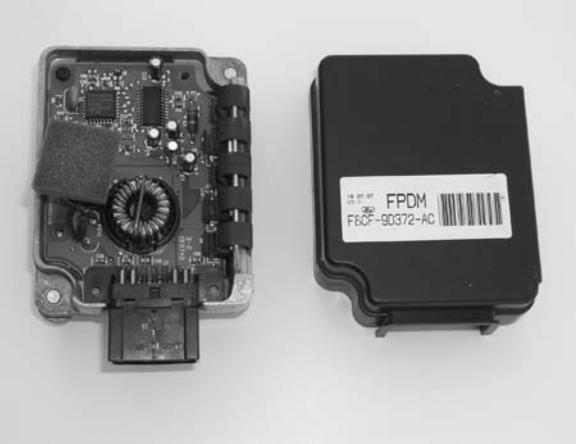


Figure 14–12 Fuel Pump Driver Module.

monitors fuel rail pressure. This sensor also monitors manifold absolute pressure (MAP) through a short vacuum hose. Thus, the resulting signal informs the PCM of the pressure differential across the fuel injectors and is therefore pertinent to the injectors' flow rate.

The PCM controls a Fuel Pump Driver Module (FPDM) (Figure 14–12), which is mounted in the trunk on passenger cars. The FPDM, like a fuel pump relay, carries the current that the fuel pump motor draws. The difference is that the FPDM is used by the PCM to control the speed of the fuel pump motor through a pulse-width modulated (PWM) signal. The PCM sends the FPDM a low-current PWM command signal (Figure 14–13). In turn, the FPDM controls the fuel pump motor according to the same PWM signal but carries the higher current flow. This design allows the PCM to vary the speed of the fuel pump to control the fuel pressure applied to the fuel injectors while watching the signal from the fuel pressure sensor on the fuel rail. The fuel pump assembly also contains a pressure relief valve (Figures 14–13 and 14–14). This system still utilizes a fuel pump relay, but the relay's only purpose is to make power available to the system.

An advantage of this design is that the fuel pressure differential across the fuel injectors may be read through the data stream with a scan tool.

Idle Air Control Valve. The idle air control (IAC) valve (Figure 14–15) is a normally closed solenoid, similar to the one used with the EEC IV system, except that it is operated by the PCM on a rapid pulse-width modulated (PWM) signal in order to control throttle bypass air. The frequency

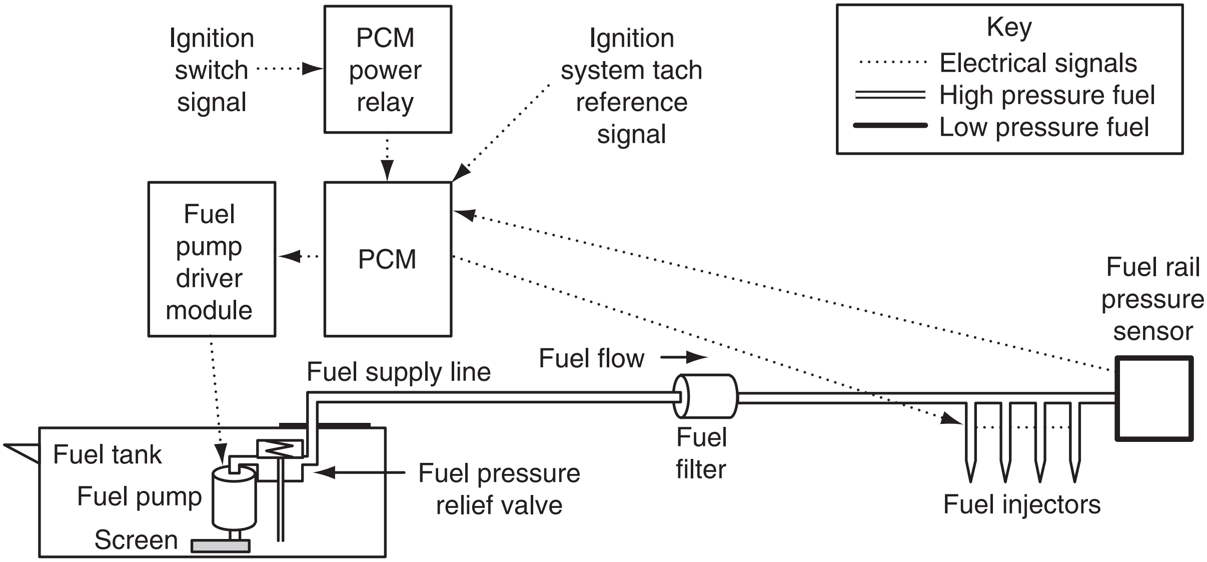


Figure 14–13 Electronic returnless fuel injection system.

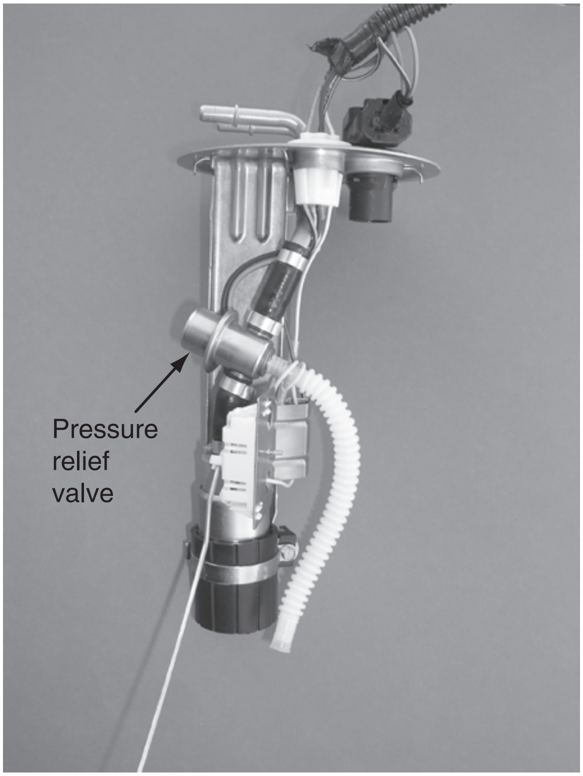


Figure 14–14 Fuel pump with fuel pressure relief valve.

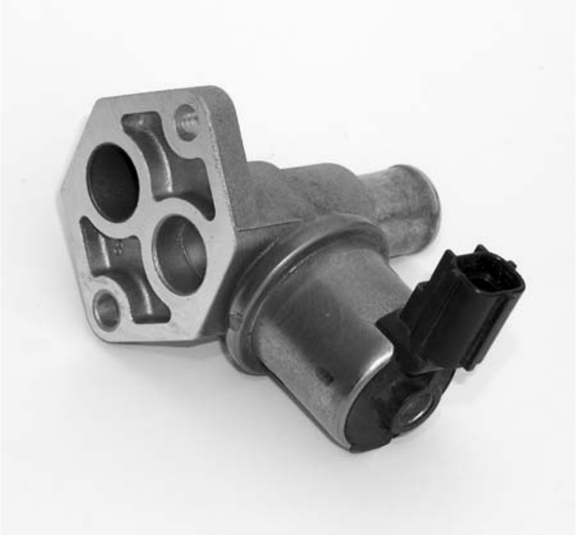


Figure 14–15 IAC valve.

of the signal is controlled by the PCM, varying from around 650 Hz to around 1500 Hz. The solenoid is not expected to open and close at this extremely high cycling rate. Rather, the on-time of the signal causes the solenoid's iron core (with the valve attached) to *float* at a designated point between fully closed and fully open. Ultimately, this high frequency PWM signal determines the amount of atmospheric air that bypasses the throttle plates.

Ignition Systems

While some TFI-IV distributor ignition systems carried over from EEC IV into some EEC V applications, by 1999 the only application that retained a distributor was the 3.3-L Villager. With the exception of the 2.0-L Probe (prior to 1999), the distributor applications continued to use a separate, dedicated ignition module to control the ignition coil. The 2.0-L Probe allowed the PCM to directly control the ignition coil.

The EDIS carried over from EEC IV into EEC V (as described in Chapter 13). The EDIS system is a waste spark system, using one ignition coil per two cylinders. A given coil fires two spark plugs simultaneously, one on a cylinder near the end of its compression stroke and the other (the "waste spark") on a cylinder near the end of its exhaust stroke. All coils are formed into one component called a *coil pack* (Figure 14–16).

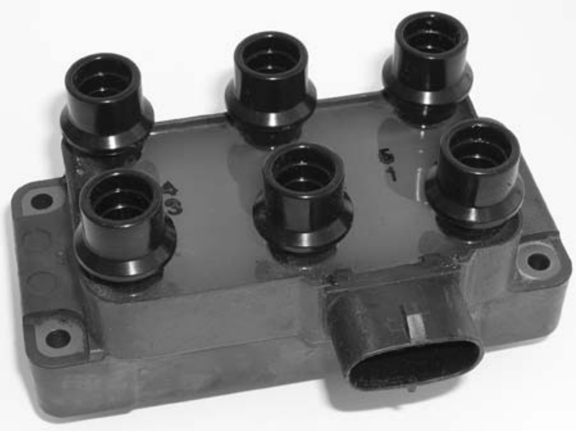


Figure 14–16 EDIS coil pack.

Most 1996 and newer EEC V EDIS applications (except for the 1996–1997 Windstar) allowed the PCM to directly control the ignition coil primary circuit, without the use of an external separate ignition module. By 1998, all EDIS applications allowed the PCM to directly control the ignition coil.

EEC V has also incorporated another format of a distributorless ignition system, commonly known by Ford as CPP. This system may also be referred to as *coil-on-plug* or COP. This version uses one ignition coil per cylinder (Figure 14–17). Each coil sits directly on top of a spark plug so that the secondary ignition wires are eliminated. The advantage of this design is that the potential for induced voltages in nearby circuits from secondary wiring has been reduced. This design was introduced on 1998 model-year vehicles and is used on such engines as the 3.0-L V6, 3.9-L V8, and Triton 5.4-L V8. However, waste spark systems still continue to be used on some engines such as the 4.0-L V6. All of the CPP systems allow the PCM to directly control each ignition coil without the use of an external separate ignition module.

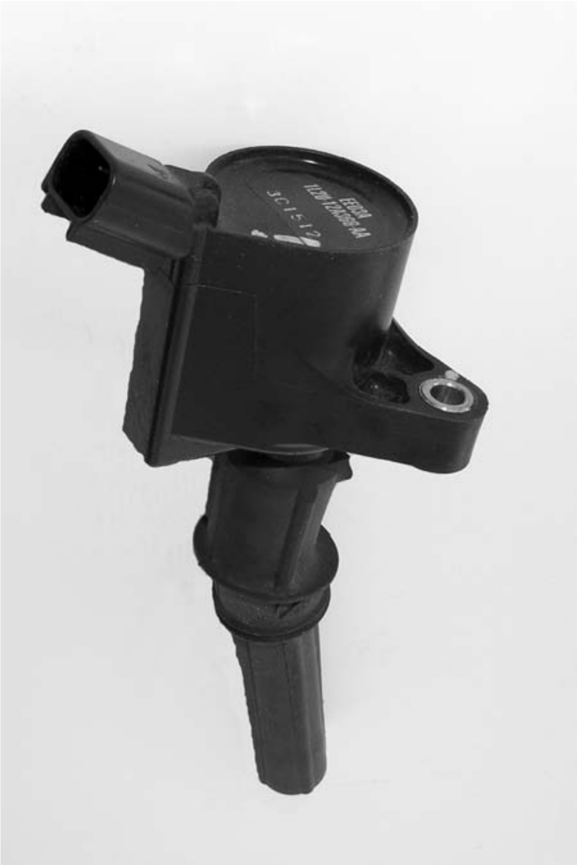


Figure 14–17 COP ignition coil.

EMISSIONS CONTROLS

Emission system components do not necessarily provide any advantage in terms of engine performance or increasing fuel mileage, but they are necessary to reduce toxic exhaust emissions. Some emissions components, like the PCV system, work independently of the engine control system and have no more connection to the PCM than the glove box latch, while others are controlled by the PCM as precisely as spark timing or the air/fuel ratio.

Secondary Air Injection

While the engine is warming up to a temperature at which the system can go into closed loop and regulate the air/fuel mixture according to the responses of the oxygen sensor, the air injection pump injects air into the exhaust manifold to burn as much residual fuel (hydrocarbons) as possible to minimize undesirable emissions (Figure 14–18). Once the engine and oxygen sensors are warm enough to go into closed loop and the oxygen sensors are capable of generating a voltage, the air injection system switches air flow to the catalytic converter. The switch from the exhaust manifold to the converter is an easy way to check to see when the system has switched to closed-loop operation.

Like other manufacturers' systems, the Ford air injection system shifts into divert mode or, with an electric air pump, shuts down the pump under circumstances when the injected air could cause backfire or damage.

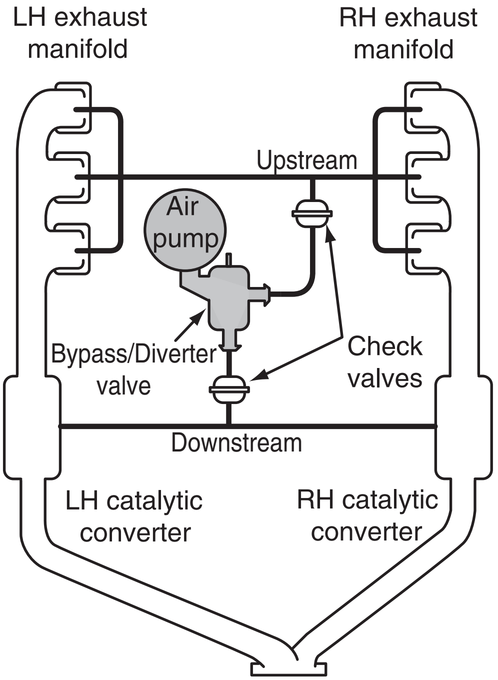


Figure 14–18 Secondary air injection diagram.

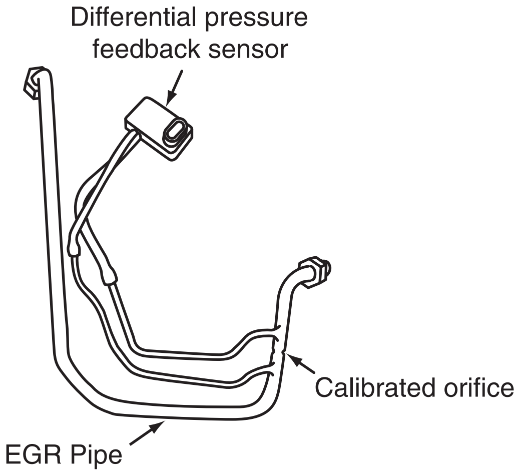


Figure 14–19 This EGR pipe assembly shows the calibrated orifice and DPFE sensor.

Exhaust Gas Recirculation System

To reduce the formation of oxides of nitrogen, or NO_x, the exhaust gas recirculation (EGR) system meters a measured amount of inert exhaust gas back through to the intake manifold. The exhaust gas (containing close to 0 percent oxygen when the system is in proper closed loop control of the air/fuel ratio) displaces incoming ambient air drawn in through the throttle body, thereby reducing the amount of ambient air (containing between 20 and 21 percent oxygen) that is drawn in by the piston. The fuel management system reduces the volume of fuel that is delivered to the cylinder proportionately. This ultimately reduces combustion chamber temperatures to below the temperature at which NO_x forms.

The Ford EEC V system uses a Differential Pressure Feedback EGR (DPFE) sensor (Figure 14–19) (also known as a Delta Pressure Feedback EGR sensor) to continuously monitor the EGR flow rate. In the EEC IV system (described in Chapter 13), the pressure feedback EGR (PFE) sensor replaced the EGR valve position (EVP) sensor because the EVP sensor could not measure actual EGR flow rate, which is, of course, affected by carbon buildup in the EGR passages. While the PFE sensor is able to measure EGR flow rate, it still could be affected if an unexpected change in exhaust backpressure occurred.

The DPFE sensor used in the EEC V system continues to monitor the pressure just before the EGR valve and after a metering orifice (which acts as a restriction to flow) placed in the exhaust passage, just as the PFE sensor did. If the EGR valve were fully closed, this would likely be a positive pressure, above atmospheric pressure. But if the EGR valve were wide open, this would likely be a negative pressure, below atmospheric pressure. In addition to measuring this pressure, the DPFE sensor also indexes this pressure value to raw exhaust pressure just before the metering orifice (Figure 14–20).

The DPFE sensor actually allows the PCM to measure the pressure drop across the metering orifice in the exhaust passage. (*This is similar in concept to how current flow in an electrical circuit affects the amount of voltage drop measured across a resistance.*) This allows the PCM to

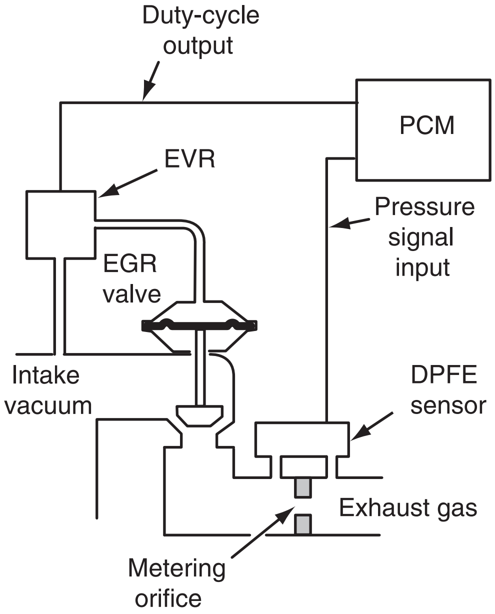


Figure 14–20 DPFE flow diagram.

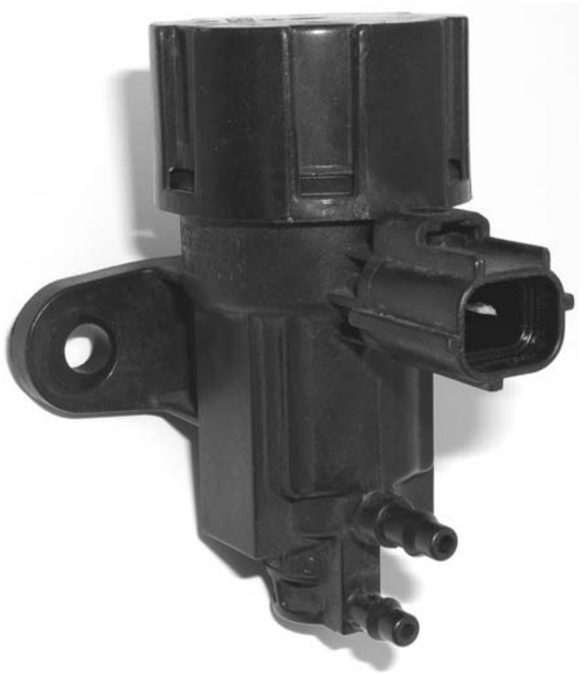


Figure 14–21 EGR vacuum regulator.

accurately know the true EGR flow rate, even if exhaust backpressure were to change. This allows the PCM to control the air/fuel ratio more precisely, due to the fact that EGR gasses displace ambient air coming into the engine. To control the EGR valve, the PCM operates an EGR valve regulator (EVR) on a duty cycle (Figure 14–21). The EVR carries over from EEC IV and is described in Chapter 13.

An updated version of the DPFE sensor was introduced in the 2002½ model year and is used on several models as of the 2003 model year. In this version, the restrictor was moved from the exhaust side of the EGR valve to the intake side (Figure 14–22). In this design, the DPFE sensor is used by the PCM to measure the difference between MAP values in the intake manifold and the pressure between the EGR valve and the metering orifice. The DPFE sensor actually measures the pressure drop across this metering orifice as it did when it was located on the exhaust side of the EGR. When the DPFE sensor sees that there is no pressure drop across the metering orifice (restriction), the PCM knows this indicates that there is no EGR flow. As EGR flow is increased, the PCM will see a greater pressure drop across the metering orifice. In addition to the DPFE signal, the DPFE sensor also sends the PCM a MAP signal. To reduce costs, Ford manufactures the EGR valve, the DPFE sensor, and the EVR into one component called an EGR System Module (ESM).

Ford Motor Company has also begun using a vacuum-less EGR valve on select vehicles (that is, it does not require a vacuum signal for operation, similar to the General Motors Digital and Linear EGR valves). This is a stepper motor that can move a total of 52 discreet increments or "steps" from fully closed to fully open to precisely control EGR flow. Its operation is monitored through the use of a MAP sensor (similar to many General Motors vehicles).

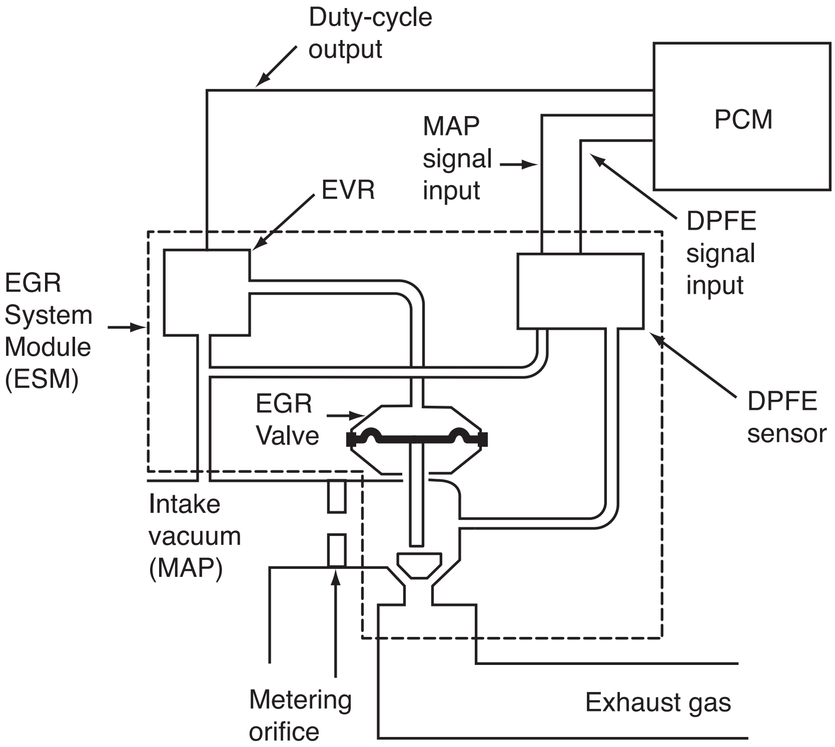


Figure 14–22 ESM assembly with an EGR valve, EVR, and DPFE sensor that monitors pressure drop across a metering orifice placed on the intake manifold side of the EGR valve.

Evaporative/Canister Purge System

To enable the PCM to meet OBD II standards, Ford added a purge flow sensor on early EEC V vehicles, located a few inches from the canister purge solenoid used by the PCM to control purging. This sensor is a thermistor that measures the cooling effect of fuel vapors as they are purged in order to know purge flow rate.

In the 1998 model year, an enhanced evaporative system added a pressure sensor to the fuel pump and sender assembly in the fuel tank (Figure 14–23). The addition of this pressure sensor allows the PCM to perform the large (gross) leak test and small leak test that OBD II standards require to verify that unnecessary hydrocarbon vapors are not reaching the atmosphere. To perform the large (gross) leak test, the PCM energizes a purge solenoid to allow a vacuum to be drawn on the fuel tank while also energizing a vent solenoid that, in turn, will prevent the tank from being vented to the atmosphere. If a momentary vacuum cannot be drawn on the fuel tank, as measured by the pressure sensor, the vehicle fails the large (gross) leak test. If the vacuum can be drawn on the fuel tank, but does not hold, the vehicle fails the small leak test. For the 2001 model year and beyond, the fuel tank must hold vacuum long enough to verify that no leaks larger than 0.020 inch are present. If the gas cap is left loose (or even left entirely off), as identified by the large (gross) leak test, newer Ford products illuminate a “Gas Cap Loose” warning lamp on the instrument panel. If the driver ignores this warning lamp for too long, the PCM will eventually illuminate the MIL and set a DTC in its memory.

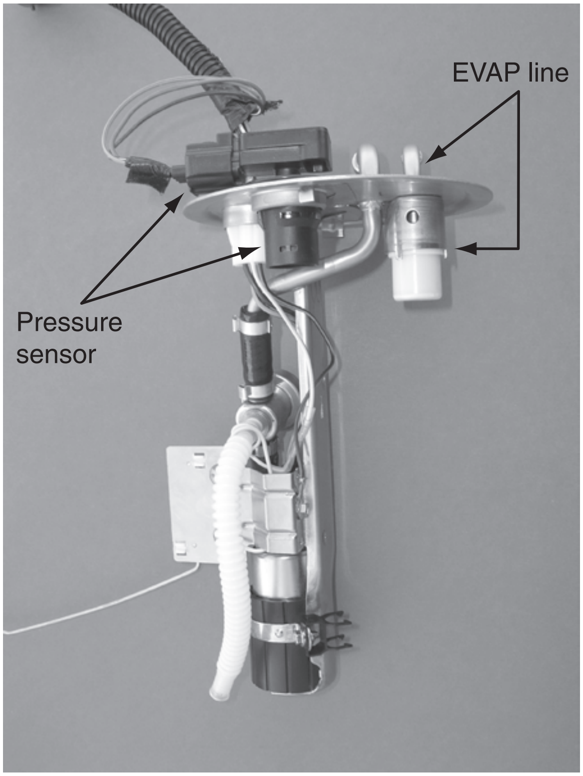


Figure 14–23 Fuel pump assembly with fuel tank pressure sensor and evaporative system line.

ADVANCED FORD COMPUTER SYSTEM FEATURES

3.9-L V8 Engine

An example of modern technology—the Ford 3.9-L (240 CID) V8 (a Jaguar derivative)—was introduced on the Lincoln LS in the 2000 model year and on the Ford Thunderbird in the 2002 model year. The 3.9-L is a 32-valve V8 with dual overhead cams. Initially having a 10.6:1 compression ratio, it was rated at 252 HP at 6100 RPM and 261 ft.-lb. of torque at 4300 RPM.

In the 2003 model year, both on the Lincoln LS and on the Thunderbird, **Variable Cam Timing (VCT)** was added to the 3.9-L V8, thereby allowing for an increase in compression ratio to 10.75:1 while maintaining the ability to burn regular octane fuel (91 octane minimum). The result was an increase in performance to 280 HP at 6000 RPM and an increase in torque to 286 ft.-lb. at 4000 RPM (also slightly reducing the RPM required to achieve peak horsepower and torque). On both vehicles, the 3.9-L V8 was coupled with an advanced electronic five-speed automatic transmission with a clutchless manual shift mode. The 2003 model year also saw the addition of electronic throttle control (ETC) as well as the CAN protocol on both the Lincoln LS and the Thunderbird. The 3.9-L V8 continues to be used on the Lincoln LS and was used on the Ford Thunderbird until its demise in July 2005.

PCM Updates

While the EEC V system was initially produced with a 104-pin connector at the PCM (as described previously in this chapter), several updated versions of this system are now being produced using PCM connectors with various numbers of terminals. Figure 14–24 shows one example of a PCM that has 150 terminals. The PCM harness connector actually consists of three separate harness connectors. A 60-pin harness connector provides the sensor and actuator circuits associated with the engine control

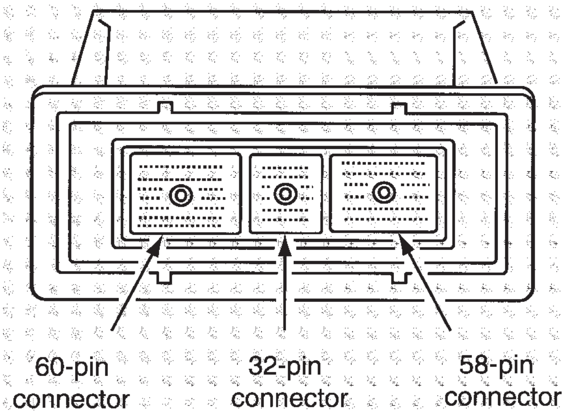


Figure 14–24 The 150-pin PCM manages engine, transmission, and support services.

system. A 32-pin harness connector in the center provides the sensor and actuator circuits associated with control of the electronic transmission. A 58-pin harness connector provides the sensor and actuator circuits associated with control of other support systems, such as the electronic speed control system. The pin connector arrangement shown in Figure 14–24 is used on the 2000 and newer Lincoln LS and the 2002 to 2005 Ford Thunderbird, all with the 3.9-L V8 engine. The same connector arrangement is also found on 4.6-L V6 applications such as the 2002 and newer Ford Explorer. There are other versions using different connector arrangements as well, such as a 150-pin PCM that uses three separate 50-pin harness connectors, but all of them still fall under the EEC V system.

Variable Cam Timing

Ford began using VCT in 1998 on a 2.0-L engine that used a cam phaser on the front end of the camshaft to change the camshaft's position relative to the crankshaft. The cam phaser is a vane type and is controlled by the PCM using an oil control solenoid to apply engine oil pressure to one side or the other of a set of vanes connected to the camshaft. This action causes the camshaft to be rotated in one direction or the other to either advance or retard cam timing. Cam timing can be advanced to provide more low-end torque or it can be retarded to provide more high-speed power. An adjustment of 60 degrees (from fully advanced to fully retarded) is provided. A pin locks the cam phaser in the fully advanced position for initial engine start-up. The addition of the VCT system allowed Ford engineers to increase compression ratios while still using regular octane fuel. Additionally, the VCT design can be used to reduce the need for an EGR system and all of the associated hardware. However, certain engines, such as the 3.9-L V8, retain the EGR system, in addition to the use of a VCT system, because of a combination of the higher compression ratio that is used, coupled with the PCM's performance strategies.

Ford defines four types of VCT systems:

1. Intake Phase Shifting or IPS: The intake cam is actively advanced.
2. Exhaust Phase Shifting or EPS: The exhaust cam is actively retarded.
3. Dual Equal Phase Shifting or DEPS: Both the intake and exhaust cams are actively and equally advanced or retarded.
4. Dual Independent Phase Shifting or DIPS: The intake and exhaust cams are independently controlled.

Initially, the 1998 2.0-L engine allowed the PCM to vary the timing of the intake camshaft (IPS). Other engines, such as the 3.9-L V8, allow the PCM to vary the timing of the exhaust camshafts (EPS). New for the 2005 model year, Ford added a VCT system on the Triton 24-valve, 5.4-L V8. This engine uses a three-valve-per-cylinder design with one overhead camshaft per bank. Each camshaft operates both the exhaust valves and the intake valves on the respective bank. The PCM varies the cam timing of these camshafts to vary the timing of both the intake and exhaust valves equally (DEPS). This is also referred to as "dual-equal variable cam timing"; it is the industry's first mass application of such a design.

Ford Motor Company suggests that, because the Triton 5.4-L V8 utilizes electronically controlled VCT along with electronically controlled spark timing, the following advantages are realized:

- A special "cold-start" strategy is programmed into the PCM, which controls the spark timing system and the VCT system to bring the exhaust temperature and catalytic converters up to operating temperature more quickly, thereby reducing cold-start emissions.
- The PCM is programmed to control the VCT system to reduce pumping losses when engine operating conditions allow. (Pumping losses are defined as the cylinders' loss of power created by having to work against engine vacuum to bring the air/fuel charge into the cylinder and having to work against

atmospheric pressure to expel the burned air/fuel charge from the cylinder.)

- The PCM is programmed to use the VCT system to channel part of the exhaust gas back into the intake manifold during certain engine operating conditions, thus reducing the need for an EGR system.
- The PCM is programmed to use the VCT system to create a higher torque curve at lower RPM without sacrificing high-end power.

Electronic Throttle Control

Ford introduced ETC in the 2003 model year on the 3.9-L V8 used on the Lincoln LS and Thunderbird. In the 2004 model year, the ETC system was added to Explorer/Mountaineer and the new light-duty F-series trucks. ETC will continue to be added to most other vehicles. The Ford ETC system, like the General Motors ETC system, physically decouples the throttle plate(s) from the throttle pedal. On the Ford ETC system, the PCM controls throttle plate movement electronically and directly while receiving input from the driver through an accelerator pedal position (APP) sensor, thus eliminating the traditional throttle cable. The ETC system is often referred to generically as a "drive-by-wire" system. The ETC system provides several advantages, including lowered emissions and quicker throttle response. Ford states that the use of an ETC system has the potential to increase fuel mileage due to a control strategy that allows the PCM to optimize fuel control with transmission shift schedules while continuing to deliver the driver-requested amount of torque at the wheels.

The components of Ford's ETC system include a **Throttle Plate Position Controller (TPPC),** a TPS to monitor throttle plate position, a DC motor that serves as the actuator used to control throttle plate position, and an APP sensor. With a cable-operated throttle plate, the TPS is said to give the PCM information concerning *driver demand*. In an ETC system, driver demand information now originates at the APP sensor.

The TPPC is a separate IC chip embedded within the PCM with the task of controlling the ETC system (Figure 14–25). Because safety is a major concern in such a system, a complex safety monitor strategy is used. This strategy involves additional hardware within the PCM, as well as additional programming strategies. The PCM's inputs are received by both the PCM's primary central processing unit (CPU) IC chip and by an additional IC chip called the Enhanced–Quizzer, or E Quizzer (Figure 14–25). The primary CPU interprets the inputs and makes decisions concerning the output functions, but the E-Quizzer redundantly monitors the inputs and the primary CPU's handling of the information.

The primary CPU decides how the throttle plate(s) should be controlled and then instructs the TPPC where to position the throttle. The TPPC controls the throttle plate(s) with a DC motor attached to the throttle body (Figure 14–26). The control signal from the TPPC is a bidirectional pulse-width modulated (PWM) signal, meaning that the polarity applied to the motor can be reversed for reversing the direction of motor movement and can also be operated on a wide pulse width or a narrow pulse width depending on how quickly the throttle plate(s) must be opened or closed.

The TPS is a two-channel potentiometer assembly (Figures 14–25 and 14–26), meaning that the TPS assembly now contains two potentiometers and sends two signals to the PCM. The TPS signal is delivered not only to the primary CPU and the E-Quizzer but also to the TPPC. This allows the TPPC to watch the position of the throttle as it also controls it (a closed-loop feedback/control circuit).

The APP sensor is a three-channel potentiometer assembly, meaning that the APP sensor assembly contains three potentiometers and sends three signals to the PCM (to both the primary CPU and the E-Quizzer). As the throttle pedal is moved from the idle position toward the WOT position, two of the APP sensor's channels increase the voltage signal from a low voltage up toward reference voltage, although the voltage signals are not an exact match at a given throttle position (they each move within a slightly different voltage range). The APP sensor's third channel has a voltage signal that moves downward as the throttle pedal is

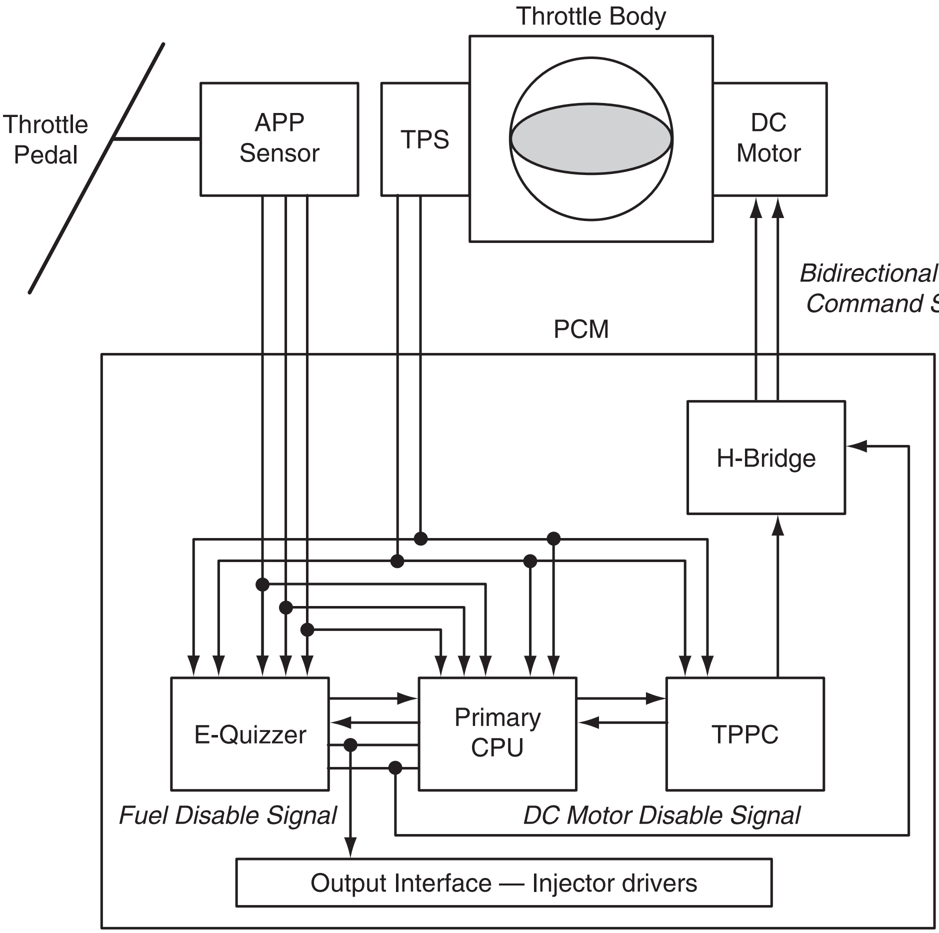


Figure 14–25 Ford's ETC system.

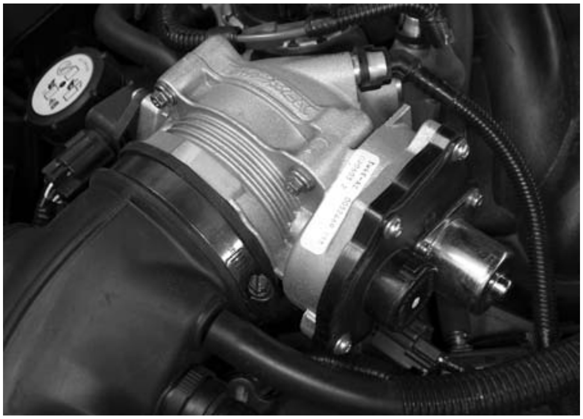


Figure 14–26 Throttle body with ETC unit and TPS.

depressed, from near reference voltage at idle down to a low voltage at WOT (thus, electrically backward from the signals from the other two channels). This allows the PCM to more precisely interpret exact throttle position than would be the case if they all delivered exactly the same voltage values at a given throttle position. The APP sensor is located in a throttle pedal assembly that is spring-loaded to give the driver a traditional pedal feel.

Compared to a cable-operated system, Ford advertises that the ETC system provides quicker throttle response. This is because a cable-operated system on a fuel injected engine allows the driver to control the volume of air allowed to enter the engine using the throttle cable, but the PCM controls the fuel. Bear in mind that to increase engine RPM and vehicle speed, both the volume of fuel and the volume of air entering the engine must be increased. In a cable-operated system, the following must happen for the PCM to know to add additional fuel:

- The driver must move the throttle pedal.
- The throttle pedal must move the throttle cable.
- The throttle cable must rotate the throttle shaft, thus opening the throttle plate(s) to allow additional air to enter the intake manifold. (Simultaneously, this action physically moves the TPS.)
- The TPS must send the PCM a signal indicating that the throttle has opened the throttle plate(s).

In an ETC system, movement of the throttle pedal operates the APP sensor directly and immediately sends the signal to the PCM to increase engine speed. Ultimately, in an ETC system, the PCM controls both air and fuel, unlike the cable-operated system in which the driver controls the air and the PCM only controls the fuel.

Utilization of an ETC system also has some other benefits:

- The PCM can use the ETC system to control engine torque directly when the traction control feature mandates it.
- The dedicated cruise control (speed control) servo is eliminated and speed control becomes a simple function of the PCM, no longer requiring additional hardware to control throttle position.
- The idle air control (IAC) solenoid is eliminated. The PCM can now control idle RPM directly without the use of additional dedicated hardware.

Intake Manifold Runner Control

The **Intake Manifold Runner Control (IMRC)** system has been used on Ford and Mazda engines in several forms. One early form (actually, a predecessor to the modern IMRC system) was first used on the Taurus 3.0-L Super High Output (SHO) engine, beginning with its introduction in the 1989 model year, and then was used on the Taurus 3.4-L SHO engine. This engine is a 24-valve V6 with two intake valves and two exhaust valves per cylinder. A long intake runner supplies air to one intake valve during normal engine RPM and load conditions. A short intake runner supplies air to the other intake valve, but it is allowed to do so only during high engine RPM and load conditions. During low RPM and load operation, a valve within the short runner is closed, inhibiting air flow through it. This design allows for good air flow velocity through the intake system and into the cylinders during low RPM and load conditions, resulting in good throttle response and greater fuel economy. However, by opening up the second runner during high RPM and load conditions, a greater quantity of air is allowed into the cylinders when it is needed for all-out performance without sacrificing the low-end throttle response.

Modern IMRC systems, as they are used on both Ford and Mazda engines, use a valve to lengthen or shorten the effective length of the intake manifold runner, depending upon engine RPM and load conditions. At low engine RPM and load conditions, the valve closes off a "shortcut," thereby effectively lengthening the intake manifold runner and making for good throttle response. At high engine RPM and load conditions, the valve opens up the shortcut, thereby effectively shortening the intake manifold runner and allowing additional air to be brought into the cylinders when more power is needed. The valve may be operated electrically by the PCM or may be operated with vacuum actuation.

Another variation of the IMRC system was a Split Port Induction (SPI) system that was used on 2.0-L Escort engines beginning in the 1998 model year. This engine has intake manifold runners of different diameters. The larger-diameter runner was closed off at engine speeds below 3000 RPM, using only the smaller-diameter runner to keep air velocity high. Above 3000 RPM the larger-diameter runner is also opened up, allowing for additional air to fill the cylinders. Even though this engine only has two valves per cylinder, its performance approaches that of engines having multiple valve heads.

The following are advantages of these designs:

- the ability to allow smaller engines to produce more power when it is needed without sacrificing low-end performance and throttle response
- the ability to sustain good low-end throttle response, greater fuel economy, and better emissions without sacrificing high-end all-out power

Bi-Fuel Systems

Natural Gas/Propane. Beginning with the Triton 5.4-L V8 in the 1998 model year, Ford began offering bi-fuel versions of some engines. These engines have specially designed components that are designed to operate either with gasoline or with natural gas or propane. The redesigned components include the throttle body, the intake manifold, and the fuel injectors.

E85 Flex Fuel Vehicle. Ford offered its first E85 flexible fuel vehicle (FFV) in the 1998 model year with the introduction of an FFV option on the Taurus with the 3.0-L engine. In the 1999 model year, the Ford Ranger was also offered with an FFV option on the 3.0-L engine. These vehicles are designed to operate on E85, pure gasoline, or any combination of the two.

Air-Assisted Fuel Injectors

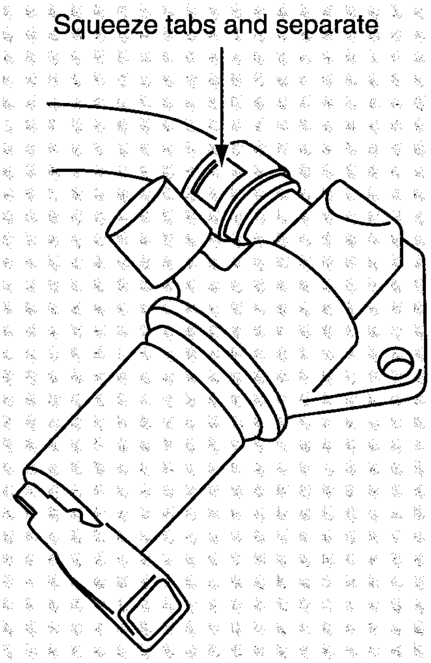


Figure 14–27 Air injection tubes are released from the idle air bypass valve by depressing the tabs.

The 3.9-L V8, used in both the Lincoln LS and the Ford Thunderbird, was initially equipped with air-assisted fuel injectors. The idle air bypass solenoid valve was modified (Figure 14–27) to route part of its bypass air to an air manifold that, in turn, routes this air to each cylinder. The air is injected at each location into the intake manifold just beside each fuel injector. This bypass air is directed at the fuel spray from each fuel injector to better atomize the fuel. Since the most bypass air is allowed through the idle air solenoid valve when the engine is cold (to maintain a proper idle RPM), this is also when the air directed at the fuel sprayed from each fuel injector will best aid fuel atomization, thus reducing cold engine emissions and improving cold-start driveability. The air hose that routes the bypass air to the air manifold can easily be disconnected from the idle air bypass solenoid valve using the quick-connect fitting (Figure 14–27).

In the 2003 model year, when the 3.9-L V8 was first equipped with the ETC system, the need for a separate PCM-controlled idle speed actuator was eliminated because the PCM now controls throttle plate position directly. With the elimination of the idle speed air bypass solenoid valve, the air-assisted fuel injector system was also eliminated.

Computer-Controlled Hydraulic Cooling Fan

The 3.9-L V8, as used in the Lincoln LS, was initially equipped with a hydraulic cooling fan. The engine drives a hydraulic pump, which supplies the fluid flow to operate the cooling fan. The pump is mounted on the right side of the engine. The fluid reservoir is located on the right fender well. The hydraulic fluid is routed through a PCM-controlled pressure variable orifice (PVO) solenoid on its way to the fan. The cooling fan runs continuously as long as the engine drives the pump. The PCM uses pulse-width modulation technology to control the fluid flow through the PVO. This fluid flow determines the speed of the fan. The system uses a special fluid, part number WSA-M2C195-A. It should not be mixed with any other type of hydraulic fluid. The hydraulic cooling fan was discontinued during the 2002 model year.

Auxiliary Coolant Pump

The Lincoln LS model is equipped with an electric auxiliary coolant pump. The auxiliary coolant pump is used whenever the dual automatic temperature control module (DATCM) requests heat. The pump increases coolant flow into the dual-zoned heater core during idle. It has a single-speed DC motor. The DATCM controls the water flow with two PWM water control valves. This eliminates the need for temperature blend doors and electric modulators. If coolant is lost and the auxiliary coolant pump runs dry, it cannot be serviced; it must be replaced.

Fail-Safe Cooling

Several Ford engines, such as the 3.9-L V8 used in the Lincoln LS and the Ford Thunderbird, are equipped with a PCM strategy called **Fail-Safe Cooling.** If the PCM senses that the engine coolant temperature has reached 260°F, it will disable two injectors at a time and allow the respective cylinders simply to pump air for the purpose of cooling the block and cylinder heads. The PCM will then alternate the pairs of cylinders that are used for cooling. This will result in a symptom of "poor engine performance" and "engine runs rough," but the driver should also be aware of over-heated condition through the temperature-warning lamp on the instrument panel. The purpose of this PCM strategy is to allow a driver to get a vehicle that has lost coolant to a service facility for repair. However, if the engine's temperature reaches 330°F, the PCM will shut down all fuel injectors until the coolant temperature drops below 310°F. This strategy will keep a driver from damaging an engine because of severe overheating. The owner's manuals on these vehicles do instruct the driver to allow the stalled engine to cool for a short time, then—upon a successful restart of the engine—to drive the vehicle to a repair facility.

The ECT sensor that is used with engines that have the Fail-Safe Cooling strategy also have a unique feature: They are of a dual range (dual temperature curve) type, similar to the dual range sensors being used by other manufacturers such as General Motors and Chrysler. The dual range ECT sensor uses a circuit in the PCM that applies voltage to the ECT sensor through a single fixed resistor within the PCM following a cold engine start. As the coolant begins to warm, the resulting reduction in the ECT sensor's resistance shifts some of the voltage drop from the sensor to the fixed resistor within the PCM. At about 170°F, the PCM completes another circuit (also with a fixed resistor) in parallel to the circuit with the primary fixed resistor (Figure 14–28). This has the effect of lowering the effective resistance within the PCM, thereby shifting much of the voltage drop back out to the ECT sensor. As the engine continues to warm and the ECT sensor's resistance continues to decrease, the voltage drop is shifted back into the PCM's internal circuits for a second time. Ultimately, this has the effect of allowing a change of more than the applied 5-V reference voltage to represent the total temperature change of the engine as it warms (Figure 14–29), thus increasing the precision of the ECT signal. By

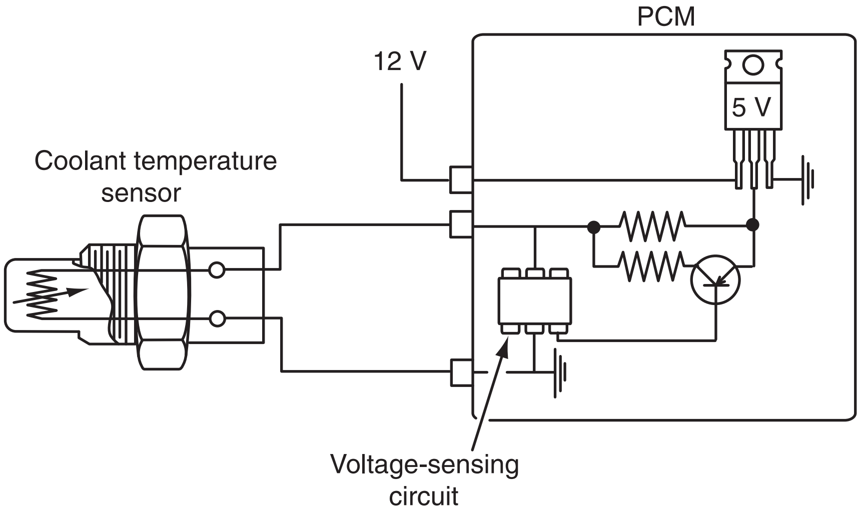


Figure 14–28 Ford dual range ECT circuit.

having the switch occur at a higher temperature (170°F) compared to other manufacturers' systems, the PCM is given greatly added precision in the upper temperature range. This extra precision in the upper temperature range is considered critical on engines that have the Fail-Safe Cooling strategy.

It should be noted that, although the PCM completes the circuit with the second resistor at about 170°F as the engine is warming, it disconnects this circuit at about 130°F as the engine is cooling.

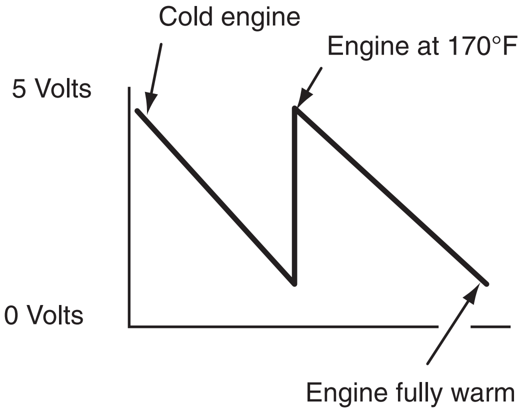


Figure 14–29 Dual range ECT sensor waveform as engine is warming up.

Adaptive Cruise Control

Ford is starting to equip certain vehicles with a new system called **Adaptive Cruise Control.** This system feeds information to the PCM and to a braking module from a radar "headway sensor" installed behind the vehicle's grille. When the cruise control is engaged, this system has the ability to reduce engine torque and even apply the brakes lightly to maintain a preset gap to a vehicle ahead. When a proper gap again appears, the vehicle automatically accelerates back to the set speed in the computer's memory. The initial system has been enhanced to provide the driver with both visual and audible warnings if a collision is imminent to let him/her know that harder braking or evasive steering is required to avoid an accident. Advantages of this system are as follows:

- It maintains a safe following distance between vehicles.
- It maintains consistent performance, even in adverse weather conditions with poor visibility.

- It maintains consistent performance, even during cornering or when road elevation changes.
- It alerts the driver by way of automatic braking.

The Adaptive Cruise Control system is optional on the Ford-built 2005 Jaguar S-Type models. For the 2008 model year, it is also available on the Ford-built Volvo S80, Volvo XC70, and Volvo V70.

Body and Instrument Control Modules

In the mid-1990s, as Ford began introducing multiplexed systems on its vehicles (see Chapter 9), other control modules were added as well. A **Generic Electronic Module (GEM)** was added to control body functions such as interval wipers, the driver's door one-touch-down power window, the illuminated entry feature, and other features. In fact, Ford's GEM is most similar to the Body Control Module (BCM) on General Motors and DaimlerChrysler vehicles, except that it does not control the climate control system.

Beginning with the 2002 model year on the Lincoln LS and the Ford Thunderbird, Ford divided the GEM into two control modules: the **Front Electronic Module (FEM)** and the **Rear Electronic Module (REM).** The FEM controls the one-touch-down power driver's window, the horn relay, and the exterior lighting at the front of the vehicle. The REM controls the exterior lighting at the rear of the vehicle, the deck lid release solenoid, and, on the Thunderbird, the passenger power window.

On the Thunderbird, the FEM and REM control the driver's and passenger power windows, respectively, so as to lower them one-half inch when the respective door is opened. The module then raises the window fully when the door has been closed again to provide good sealing with either the hardtop when it is in place or with the soft convertible top when it is in place. The driver is able to calibrate this feature by lowering each front window fully and then continuing to hold the switch depressed for at least 2 seconds after the window has hit bottom. Then the driver must raise the window fully and, again, continue to hold the switch depressed for at least 2 seconds after the window is fully up. The FEM is able to determine the window's position by the fact that when the window reaches an extreme and the circuit continues to be completed, the current draw for that window's motor increases substantially due to the added mechanical resistance. This calibration allows the FEM to know the exact position of the window. Then, when a door is opened, the module counts the motor's current pulses in order to lower the window the prescribed amount.

GEM system modules previously used a similar concept. It is through the increase in current flow that the GEM knows when a one-touch-down window has hit bottom. If the window's track is misadjusted or lacks lubrication, causing current flow to rise prematurely, the GEM will deactivate the one-touch-down feature prematurely, resulting in a driver complaint.

An additional control module, the instrument panel controller (IPC), not only controls the instrument cluster gauges and warning lamps but also controls the electronic tilt and telescopic steering column. On some models, such as the 2002–2005 Ford Thunderbird, the IPC moves the steering column fully up and in as an easy-exit feature when the ignition key is removed from the lock cylinder.

Voice Recognition/Navigational Systems

Ford Motor Company introduced a combination voice recognition/navigational system on 2004 model-year Lincoln Navigators and Aviators. This early system had a limited vocabulary and limited features. The 2005 model-year Lincoln Navigators and Aviators have a combination voice recognition/navigational system that is greatly enhanced in its capabilities. On this system, the driver presses a button on the steering wheel labeled "VOICE" (Figure 14–30)

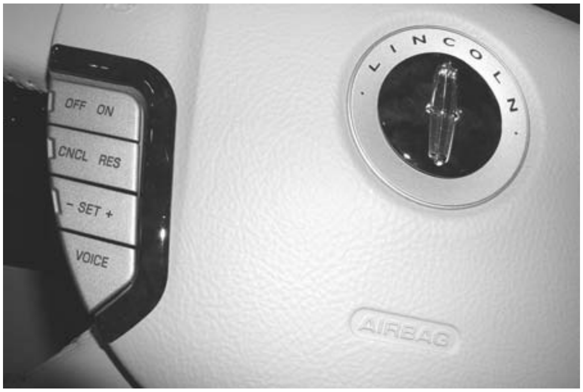


Figure 14–30 Lincoln "VOICE" button on steering wheel.

and then follows with verbal instructions for the navigational system or for several other on-board systems.

In itself, the navigational system is a mapping system, similar to a "streets and trips" program that you might install on a PC. Such a program can quickly choose the best route between two points on a map. For example, if you enter your current position as your home address and then enter another address that you wish to travel to, the program will quickly give you turn-by-turn instructions for getting to your destination. As a navigational system on a vehicle, the system's control module uses the Global Positioning System (GPS) to determine the vehicle's current position, heading, and speed. The driver can use either a text entry (if the vehicle is stopped) or a voice entry to enter a desired destination, either an address or a point of interest. Points of interest that are programmed into the system include restaurants, gas stations, and ATMs.

Voice entry of a desired destination is achieved by depressing the "VOICE" button on the steering wheel and then speaking the desired destination address or point of interest aloud. Ford Motor Company has brought voice recognition technology to a new level with its advanced **Conversational Speech Interface Technology.** Equipped with a 50,000-word vocabulary, this technology allows the driver and/or passenger to carry on a normal dialogue with the vehicle. A text-to-speech system is used, but the resulting dialogue on the part of the vehicle sounds more like a real person than a robot. As a result, the driver/passenger does not have to memorize specific voice commands as with some voice recognition systems. The voice recognition system's control module is multiplexed to other computers on the vehicle (see Chapter 8). As a result, many systems can be controlled by voice, including the navigation system, the entertainment system, the climate control system, and the retractable sunroof. For example, the driver or passenger can use voice commands to select climate control fan speed, desired temperature, and operating modes.

Personalization preferences for multiple drivers can also be configured through voice commands. These preferences include favorite music selections, style of the visually displayed graphics, and even the type of voice that is used by the vehicle to communicate with the driver/passenger.

The Conversational Speech Interface Technology allows everyday language to be used, but if the voice recognition control module does not fully comprehend a voice command, it is programmed to ask for more information. For example, when asked to look up a phone number, if it finds several results that seem to fit the original request, it will ask for additional information. However, the voice recognition system will only speak when spoken to.

If asked to play music, the control module will ask for a music type and then list the artists that fit the request. Volume can also be controlled through the voice recognition system. Music can be downloaded to an on-board computer in the MP3 format using Bluetooth™ wireless technology. The music may be downloaded from a PDA, cell phone, or laptop computer that is turned on and located within the vehicle. Similarly, personal files, including phone lists and Internet addresses, may also be downloaded to the on-board computer.

Intelligent Architecture

Because people "spend a great deal of time in their vehicles," Ford Motor Company engineers are designing software/hardware systems into the vehicle designed to make life easier. Known as **intelligent architecture,** early versions of this system first appeared on 2003 Lincoln Aviators. Today, these systems include the combination voice recognition/navigational system just described, including the ability to personalize driver settings and to download information or music in the MP3 format to an on-board computer from a personal computer, PDA, or cell phone using Bluetooth wireless technology. Also included is real-time navigation, a feature that can alert the driver to an accident ahead or even remind him/her of a vehicle service that is due.

Another feature, called "MyHome," gives the driver the ability to communicate with Web-based equipment at home, such as a Web-based refrigerator that might upload an electronic grocery list to the vehicle's on-board computer for display on the navigational system screen. This same feature could also allow a driver to control a home sprinkler system, arm or disarm a home security system, review an appointment calendar, and even check information on a flight while trying to get to the airport on time.

A diagnostic feature also allows the driver to connect the vehicle to an online diagnostic center, providing information as to current problems found in the primary electronic control systems of the vehicle. It can even allow the driver to locate nearby dealerships and to schedule an appointment.

SyncMyRide

For the 2008 model year, Ford Motor Company is offering several vehicles that use Bluetooth wireless technology to enable a Bluetooth-enabled cell phone or media player to be controlled via the vehicle's voice recognition system. This is advertised by Ford as their "SyncMyRide" feature. The software that supports this feature is provided to Ford by Microsoft. The driver is able to use the voice recognition system to place a hands-free phone call or to make a request for a particular genre of music stored in his/her media player.

AdvanceTrac™ System

Added to model year 2003 Explorers and Expeditions (and their Mercury counterparts), the **AdvanceTrac™** system is a modified antilock brake and traction control system with collision avoidance in mind. This system receives input from seven sensors, monitoring such things as steering wheel angle, throttle position, wheel speed, and the vehicle's yaw rate (basically a determination of how far left or right a vehicle has moved from its intended course, and what might happen if the vehicle were to understeer or oversteer its intended path). If the vehicle's back end begins to fishtail (oversteer), the system detects this and applies a braking pulse at the outside front wheel to help the driver stabilize the car. (This action allows the side of the vehicle on the inside of the turn to begin to pass the other side, thus reducing the level of oversteer.) If the front end of the vehicle begins to drift to the outside of a turn (understeer), the system detects this and applies a braking pulse to the inside rear wheel. (This action allows the side of the vehicle on the outside of the turn to begin to pass the other side, thus reducing the level of understeer.) With either understeer or oversteer, the AdvanceTrac system can command the PCM to reduce engine torque as needed to help prevent loss of vehicle control or rollover.

Keep in mind that antilock brake systems, traction control systems, and AdvanceTrac systems cannot overcome the laws of physics. Just as the presence of an antilock braking system does not allow the driver to stop efficiently once the tires have already hydroplaned, so the AdvanceTrac system may not be able to prevent loss of vehicle control if the driver's actions are severe enough. If the AdvanceTrac system has become activated, it is always an indication that one or more tires have lost their traction with the road's surface.

Fire Suppression System

The Ford Crown Victoria Police Interceptor (CVPI) has become the dominant police vehicle used throughout the United States because of its features, its overall performance, and its safety record. Today, the Ford CVPI accounts for more than 80 percent of all police vehicles used in North America. In Ford's efforts to make the CVPI even safer, the company has added an available option to the vehicle beginning in the 2005 model year: a fire suppression system. This system uses a liquid fire suppressant, which was chosen over foams and powders based on its ability to spread quickly and cover the gasoline as it spreads beyond the reach of the nozzles that spray the liquid suppressant. Ford engineers tested eight competing fire suppression systems and added the technology to automatically trigger the fire suppression deployment system upon a rear-end collision.

The fire suppression system uses technology similar to that used by air bag systems to automatically make the decision to disperse the liquid fire suppressant when a rear-end collision is sensed. Simultaneously, a surfactant material is dispersed through the system's nozzles, which reduces the surface tension of the liquid fire suppressant, enabling it to spread more quickly to cover any liquid gasoline as it spreads. The system may be deployed:

- Automatically, when a high-speed, high-energy impact has been sensed at the rear of the vehicle.
- Manually, when other situations might require that the driver be able to deploy the system. (Manual deployment can be achieved by the driver depressing a covered manual activation switch located on a console on the headliner, between the visors.)

✔ SYSTEM DIAGNOSIS AND SERVICE

Many of the diagnostic concepts that Ford utilized in the EEC IV system (described in Chapter 13) were carried over into the EEC V system. EEC V also integrated the required OBD II standards. As a result, the EEC V system surpasses past systems in its ability to help the technician diagnose the system.

Manual methods of code pulling are eliminated with this OBD II system. That is, connector terminals at the data link connector (DLC) (located under the left end of the instrument panel as specified by OBD II standards) should never be shorted with a jumper wire; instead, a scan tool should always be used.

Diagnosis should begin by connecting Ford's New Generation Star Tester (NGS), Worldwide Diagnostic System (WDS), Portable Data System (PDS), or other OBD II generic scan tool to the DLC. Once the scan tool has been programmed with the VIN information, a menu displays all the diagnostic features available for the particular application. These features include a Key On, Engine Off (KOEO) on-demand self-test, a Key On, Engine Running (KOER) on-demand self-test, the ability to pull continuous memory DTCs from the PCM's memory, and the ability to use the scan tool to erase continuous memory DTCs. No longer must a KOEO self-test be performed to pull continuous memory DTCs (as with the EEC IV system described in Chapter 13). Instead, continuous memory DTCs now appear in the scan tool's menu as a separate menu item. Continuous memory DTCs should always be erased with a scan tool, never by disconnecting the battery.

Ford's Quick Test for the EEC V system is defined as consisting of the following items:

- visual check
- vehicle preparation and equipment hookup
- KOEO on-demand self-test
- KOER on-demand self-test
- pulling continuous memory DTCs

About the only functional test that carried over from the EEC IV system is an active command mode (somewhat similar to the EEC IV output state check, though much more sophisticated) that allows a technician to command the PCM to energize/de-energize various actuators, although a scan tool must now be used. Several actuators have been added to what the EEC IV system allowed the technician to command.

A parameter identification mode is available to allow the technician to access certain values, analog and digital inputs/outputs, calculated values, and system status information. Other diagnostic features added include an On-Board System Readiness (OSR) test that allows the technician to view the status of all OBD II monitors (see Chapter 8 for more information on OBD II) and whether they are complete or incomplete. Incidentally, Ford has a unique DTC, P1000, that indicates if the OBD II monitors have not been completed since the last battery disconnect or erasing of codes. Also, per OBD II standards, Freeze Frame/Snapshot data is also available with any stored DTCs by accessing the generic OBD II feature on the scan tool's menu. This data allows the technician to learn what many of the sensors were reporting when a fault occurred, as well as other pertinent information such as fuel trim values.

Other modes described in Chapter 8 can be accessed through the generic OBD mode of an OBD II scan tool. For example, Mode $06 data for non-continuous monitors may be accessed in this mode. Ford Mode $06 information is available on the International Automotive Technician's Network (IATN) Web site at http://www.iatn.net.

Also, most of the procedures used to pull continuous memory DTCs, run KOEO on-demand tests (or even KOER on-demand tests in some cases), and look at data stream parameter identifications (PIDs) and values apply to other control modules on the vehicle including the GEM, FEM, REM, IPC, audio system, climate control system, and modules that control the antilock braking system and passive restraint system. In fact, some modules such as the FEM allow the technician to see four PIDs as they apply to each circuit they control. For example, if you look at the PIDs for the left front high beam headlight, the scan tool will indicate:

- whether the circuit is activated
- whether the circuit is open
- whether the circuit is shorted to power
- whether the circuit is shorted to ground

This is in addition to being able to run an on-demand test of the circuits that the FEM controls.

All this diagnostic programming is not limited to the PCM, however: It applies as well to most other control modules on today's vehicles.

SUMMARY

In this chapter we have covered most aspects of the EEC V system, including its sensors and actuators, as well as the fuel injection, spark management, and emissions systems that are under control of the EEC V PCM. This includes updated sensors such as Ford's newest DPFE sensor and the ESM of which it is part.

We took a look at the Ford 3.9-L V8 and some of the advanced features that began with that engine and are now found on other applications as well, including Variable Cam Timing and Electronic Throttle Control (ETC). We also covered the Intake Manifold Runner Control system.

In this chapter, we also covered other advanced systems such as Ford's Fail-Safe Cooling, Adaptive Cruise Control, and the differences between a GEM, a REM, and a FEM. We also took a look at some of the newest technologies, including Ford's voice recognition and navigational system, the Intelligent Architecture technology, the AdvanceTrac system, and the fire suppression system used on the CVPI.

▲ DIAGNOSTIC EXERCISE

An EEC V vehicle is towed into the shop. The complaint of "engine cranks, but won't start" is verified. One technician prepares to test the ignition system for spark using a spark tester. Another technician prepares to connect a fuel pressure gauge to the fuel rail to test fuel system pressure. What easier check are these technicians forgetting that should be performed first?

Review Questions

1. Technician A says that the EEC V PCM is able to determine the gradual wear and aging of the vehicle that occurs over time. Technician B says that the EEC V PCM is able to compensate for gradual wear and aging of the vehicle by making adjustments in its programs. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. What type of sensor does the EEC V system use to measure engine load?
   A. Vane air flow (VAF)
   B. Manifold absolute pressure (MAP)
   C. Mass air flow (MAF)
   D. Pressure feedback EGR (PFE)
3. Technician A says that the purpose of the oxygen sensor located after the catalytic converter is to measure the amount of unburned hydrocarbons that were not oxidized by the converter. Technician B says that the purpose of the oxygen sensor located after the catalytic converter is to monitor the catalytic converter's effectiveness. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
4. The power steering pressure (PSP) switch input primarily affects the PCM's control of which of the following?
   A. Idle speed
   B. Injector pulse width
   C. Spark timing
   D. The fuel pump relay
5. Technician A says that the crankshaft position (CKP) sensor allows the PCM to identify which pair of pistons is approaching TDC, enabling it to fire the correct ignition coil in the waste spark ignition system. Technician B says that the camshaft position (CMP) sensor provides the PCM with the information needed for fuel injection sequencing with the engine's firing order. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
6. What is the purpose of the inertia switch used in the EEC V system?
   A. To disable the starter circuit in case of impact
   B. To remove power from all fuel injectors in case of impact
   C. To shut down the ignition system in case of impact
   D. To shut off the fuel pump in case of impact
7. An EEC V vehicle is brought into the shop with a fuel injection system that vents fuel past a pressure regulator through a return line back to the fuel tank. Technician A says that the fuel pressure regulator is indexed to manifold pressure (vacuum) to increase the flow rate of the injectors while under heavy load. Technician B says that the fuel pressure regulator is indexed to manifold pressure (vacuum) to maintain a constant pressure differential across the injectors to maintain a constant flow rate any time the injectors are energized. Who is correct?
   A. Technician A only
   B. Technician B only

   C. Both technicians
   D. Neither technician
8. What is the primary purpose of designing a vehicle with an electronic returnless fuel injection system?
   A. To reduce vapor lock potential
   B. To reduce how much engine compartment heat is transferred to the fuel tank
   C. To increase fuel economy
   D. To increase engine performance
9. What is the primary advantage of a CPP (COP) distributorless ignition system?
   A. The PCM has more accurate control of ignition timing than with a waste spark ignition system.
   B. The potential for secondary voltage to induce a voltage in a nearby circuit has been reduced.
   C. Mounting ignition coils over the spark plugs make the plugs easier to change at the recommended service intervals.
   D. CPP (COP) systems can continue to operate if the crankshaft position (CKP) sensor were to fail.
10. When does the secondary air injection system direct air flow to the exhaust manifold(s)?
   A. During engine warm-up
   B. During closed-loop operation
   C. During heavy load conditions when the air/fuel mixture is rich
   D. All of the above
11. Technician A says that the DPFE sensor measures the physical position of the EGR valve and cannot compensate for reduced EGR flow rate caused by carbon buildup. Technician B says that a DPFE sensor measures EGR flow rate and is even able to compensate for changes in exhaust backpressure. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
12. If engine temperature rises above 260°F on a vehicle with the fail-safe cooling strategy, the PCM will do which of the following?
   A. Turn off one fuel injector at a time until engine temperature drops
   B. Turn off two fuel injectors at a time until engine temperature drops
   C. Turn off three fuel injectors at a time until engine temperature drops
   D. Turn off all fuel injectors until engine temperature drops
13. Which of the following systems allows an engine to use a higher compression ratio while still being able to use regular octane fuel?
   A. VCT
   B. ETC
   C. IMRC
   D. SPI
14. In the Ford ETC system, what component within the PCM redundantly monitors the inputs and the primary CPU's handling of the information?
   A. TPPC
   B. E-Quizzer
   C. APP sensor
   D. H-Bridge
15. On a 2002–2005 Ford Thunderbird, what does Ford call the electronic control module that controls the one-touch-down power window, the horn relay, and the exterior lights at the front of the vehicle?
   A. BCM
   B. GEM
   C. REM
   D. FEM
16. When compared with other voice recognition systems, all except which of the following are advantages of Ford's Conversational Speech Interface Technology?
   A. It allows the driver and/or passenger to carry on a normal dialogue with the vehicle.
   B. It requires that the driver and/or passenger memorize selected voice commands.
   C. Voice commands may be used to control the climate control system.
   D. Voice commands may be used to control the retractable sunroof.

17. If the front end of a vehicle with the AdvanceTrac system begins to drift to the outside of a turn, which wheel will the AdvanceTrac system apply a braking pulse to in order to correct the understeer?
    A. Inside rear wheel
    B. Inside front wheel
    C. Outside rear wheel
    D. Outside front wheel
18. In what model year did Ford begin offering the fire suppression system as an option on the CVPI?
    A. 1998
    B. 2003
    C. 2005
    D. 2006
19. Technician A says that when diagnosing an EEC V system, DTCs may be pulled manually by connecting a jumper wire between two terminals at the data link connector (DLC). Technician B says that when diagnosing an EEC V system, to perform either self-test or pull continuous memory DTCs, an OBD II scan tool must be used. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
20. On the EEC V system, Ford's DTC P1000 indicates which of the following?
    A. The PCM has failed and should be replaced.
    B. The PCM has detected a fault on the input side that should be diagnosed and repaired.
    C. The PCM has detected a fault on the output side that should be diagnosed and repaired.
    D. The PCM has not seen the OBD II monitors completed since the last battery disconnect or erasing of codes.

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Chapter 15

Chrysler Corporation Fuel Injection Systems

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Describe the various Chrysler systems and PCMs used with fuel injection, as well as their operating modes.
- ☐ Define the inputs used with a Chrysler fuel injected system.
- ☐ Define the outputs controlled by a Chrysler fuel injected system.
- ☐ Identify the two multiplexing systems used on Chrysler vehicles.
- ☐ Understand how a Chrysler fuel injected system is designed to be put into self-diagnosis, as well as the various diagnostic features, in both pre-OBD II and OBD II systems.

KEY TERMS

Adaptive Memory
Direct Ignition System/Waste Spark Ignition
Hall Effect Pickup
Inductive Pickup
Limp-In Mode
Logic Module
Multipoint Fuel Injection
Power Module
Sequential Fuel Injection
Single-Point Fuel Injection

In 1972, Chrysler became the first auto manufacturer to switch from a mechanical points-and-condenser ignition system to electronic ignition (EI). In 1976, Chrysler introduced an electronic spark control system. So the company was ready with a computer-controlled engine system in 1979 when it began systematic installation of an oxygen sensor feedback system on many vehicles. The first such system was on the California models with the slant-six engine, which combined the earlier Chrysler spark control system with an oxygen sensor with a module that controlled an air/fuel mixture control solenoid. The next year the system was extended to four- and eight-cylinder engines as well. By 1981 it was applied to federal-specification vehicles, too. By that date, it also had idle speed control functions along with EGR and air-injection actuation. As the system developed, the shift indicator light, the radiator cooling fan, and the vacuum solenoid controlling the carburetor secondary barrel on cars built for high altitudes all followed.

Chrysler produced a few Imperials with an electronic fuel injection system in the early 1980s, but the first current versions of Chrysler fuel injection appeared on the 1984 2.2-L engines. These were the **single-point fuel injection** system, which Chrysler calls Electronic Fuel Injection (EFI), and the **multipoint fuel injection** system, which Chrysler calls Multi-Point Injection (MPI). The 2.2-L MPI system is often called the *turbo* system because it uses a turbocharger. Since the original engine offerings, however, other power plants have come with either the EFI or the MPI system. The two systems are quite similar, so this chapter covers them together, pointing out variations between the two.

Before 1986, the single-point system used high fuel pressure, about 36 PSI. In 1986, a low-pressure (14.5 PSI) injector with a ball-shaped valve replaced the previous unit with its pintle-style valve. This lower pressure injector is found on many other fuel injection systems besides Chrysler's.

POWERTRAIN CONTROL MODULE

Logic Module/Power Module

From 1984 to 1988, two separate modules controlled the Chrysler fuel injection systems. The **logic module** with the central processor was inside the passenger compartment (Figure 15–1). The **power module** controls the actuators by switching the ground-side circuits for the ignition coil, fuel injector or injectors, and the automatic shutdown (ASD) relay (Figure 15–2).

The logic module gets most of its electric power from the power module; there is a separate circuit through a fuse for memory retention. The logic module sends a 5-V reference signal to its sensors and makes all the system's calculations (Figure 15–3).

Besides controlling the actuators, the power module also controls the charging system (beginning in 1985). It does so by providing ground for the alternator's field coil. Because all the actuator and alternator circuits are of relatively high current compared to the information signal currents in the logic module, the power module is separate; it is located in the engine air intake tube to carry off the heat these high-current transistors produce.

The logic module signals the power module when to open and close the primary ignition circuit and when and for how long to turn on the injector/injectors. The power module also provides a constant 8 V to the logic module and to the distributor **Hall effect pickup** unit.

When the ignition switch is on (run), it powers the power module through a fused circuit. Chrysler literature refers to this circuit as *J2.* On the printed circuit board of the power module is a rail that acts as a fuse, protecting the module

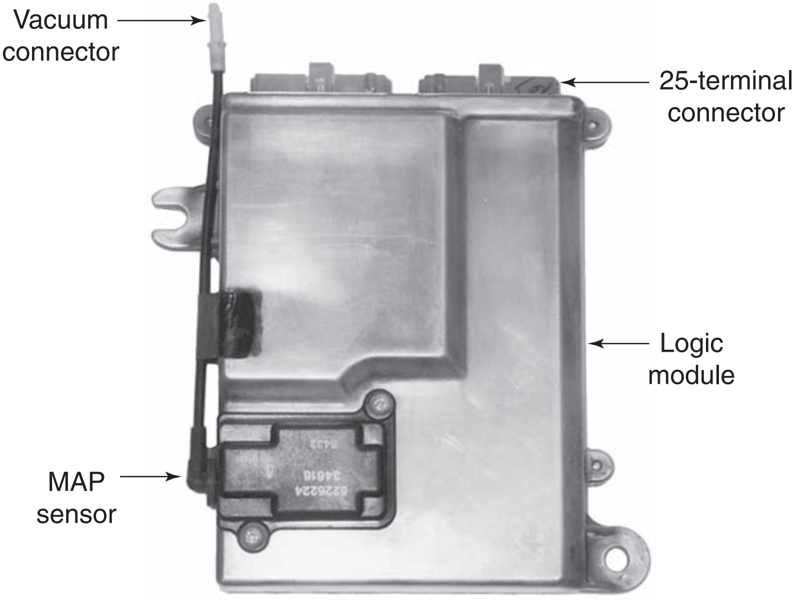


Figure 15–1 Logic module.

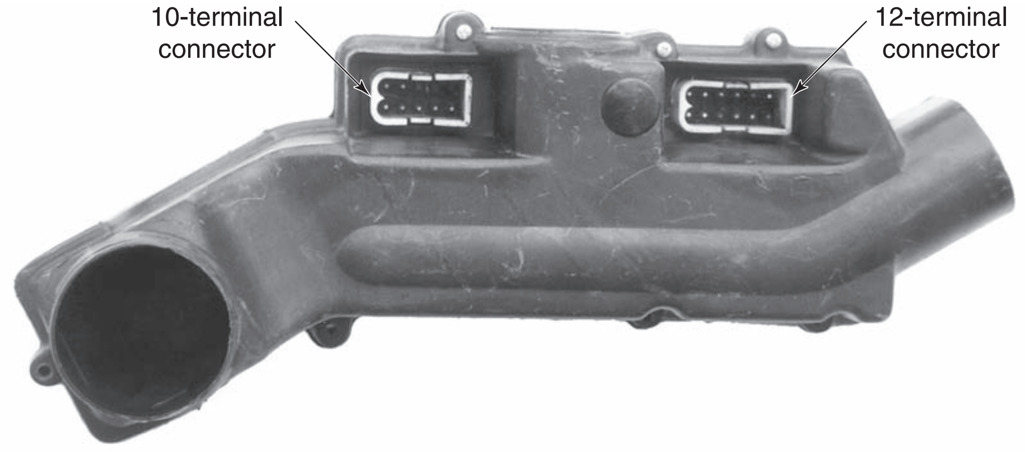


Figure 15–2 Power module.

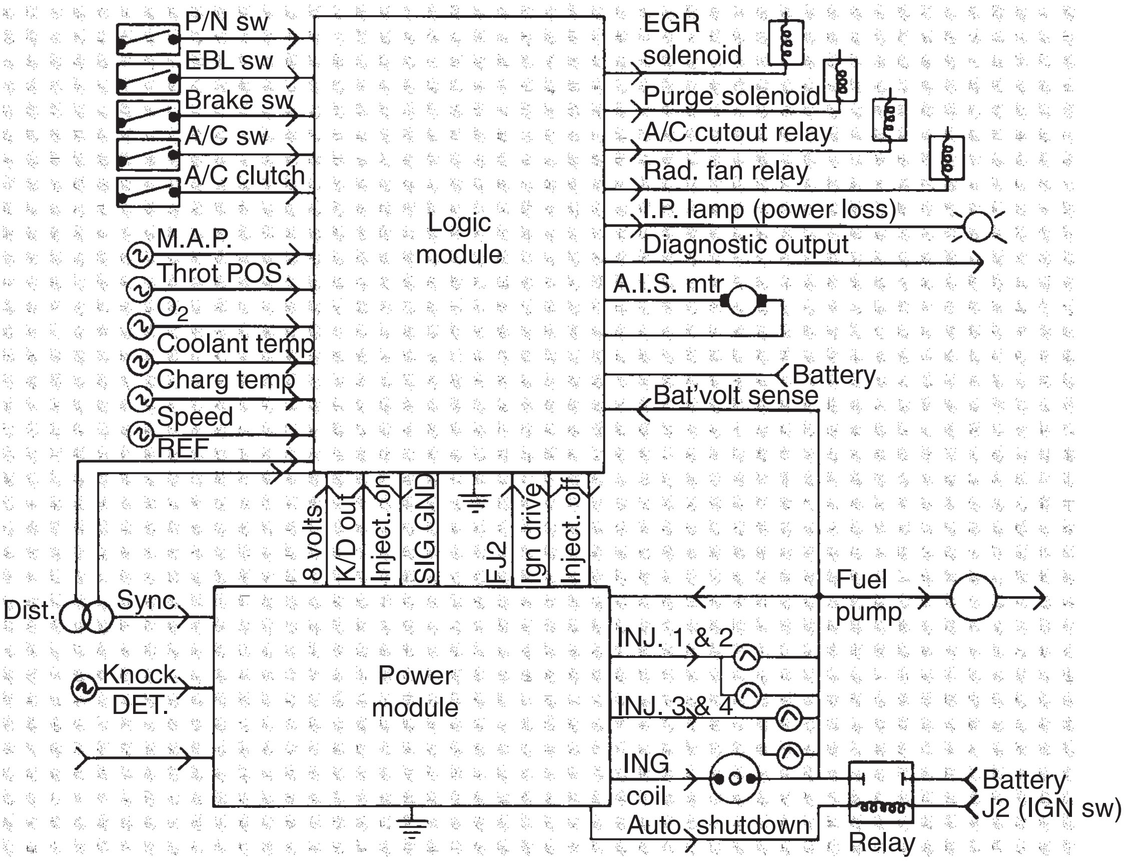


Figure 15–3 A 2.2-L turbo EFI system schematic. (Courtesy of Chrysler Corp.)

against reversed polarity. Should a reversed polarity occur, the fuse will burn open. A reserve circuit with a diode continues to supply J2 power to the power module with a slight voltage drop because of the resistance of the diode.

Single-Module Engine Controller

In mid-1987 in some 3.0-L engine applications, the logic module and the power module were both placed as separate printed circuit boards in a single unit known as the *Single-Module Engine Controller (SMEC)*. Physically, the power module is placed in a cavity created within the logic module; the two modules are then contained within a single housing. Engine intake air flows through the modules' housing to remove heat generated by the modules. Jumper wires are run between the two modules' connectors (Figure 15–4). Together, of course, these two modules constitute the PCM. By 1988, most Chrysler vehicles used the SMEC system.

The only significant technical change is the increase to between 9.2 and 9.4 V at the logic board component of the SMEC. It uses a different kind of transistor (metal oxide semiconductor field effect transistor) on the power board, which requires the higher voltage. The battery temperature sensor—used by the system to calculate the proper charging voltage—had been moved to the logic board.

Single-Board Engine Controller

In 1989, Chrysler introduced a system that combined the two separate printed circuit boards of the SMEC system by forming all components onto a single circuit board. This system was given the name *Single-Board Engine Controller (SBEC)*. The SBEC PCM is also located in the engine compartment to allow engine intake air to carry heat away from it. The SBEC PCM is recognizable by its single electrical connector (Figure 15–5). By 1990, most Chrysler vehicles used the SBEC system.

In 1991, Chrysler introduced its second generation of SBEC, known as SBEC II. By 1992, most Chrysler vehicles used the SBEC II system, including passenger cars, minivans, light trucks, and Jeeps. The SBEC II PCM still required intake air flowing through it for cooling.

In 1995, as OBD II standards were being set in place, Chrysler replaced the SBEC II system on its passenger cars and minivans with the SBEC III system. The SBEC III PCM is contained

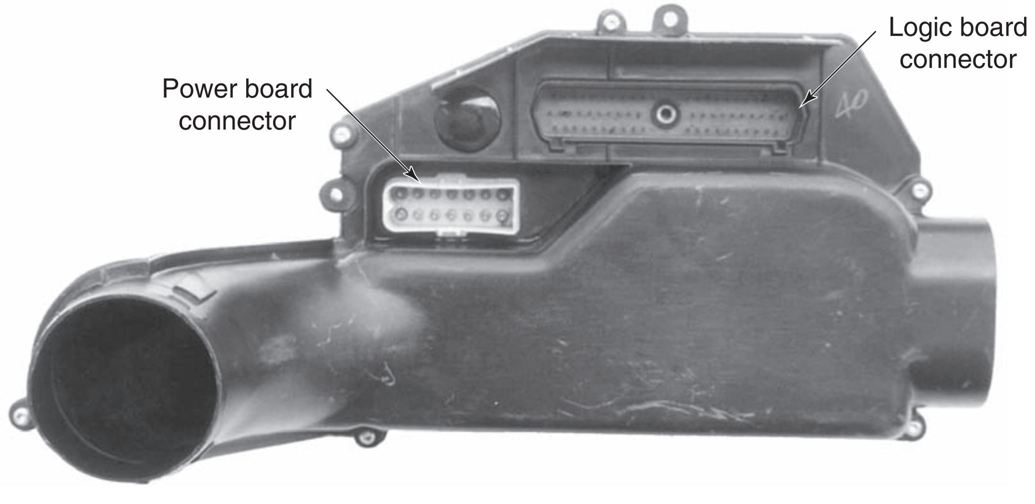


Figure 15–4 SMEC PCM.

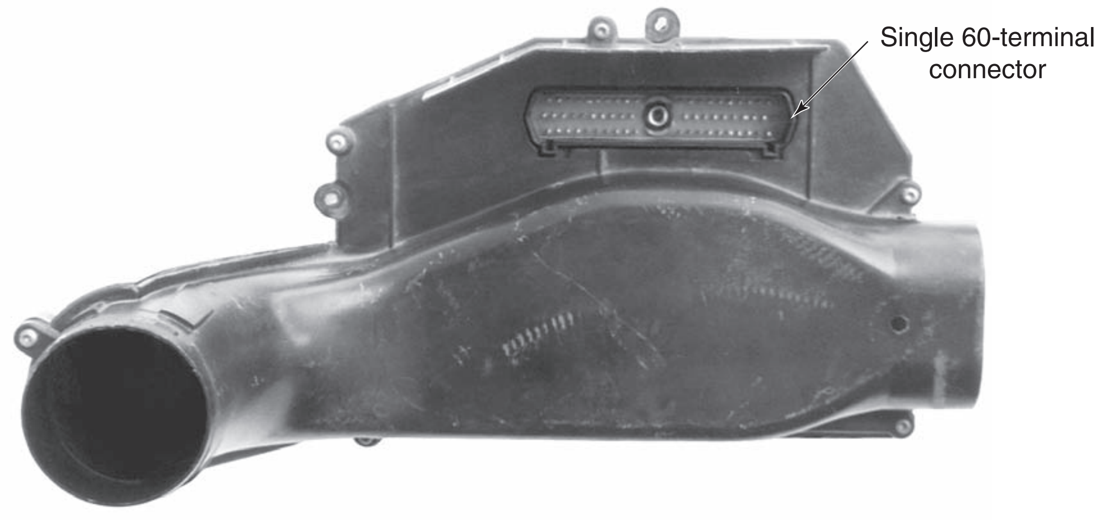


Figure 15–5 SBEC PCM.

in a shielded case to prevent electromagnetic interference (EMI) and radio frequency interference (RFI). In addition, the SBEC III case dissipates heat through external aluminum fins so that it no longer requires intake air for cooling. In 1996, Chrysler also replaced the SBEC II system on Jeeps, Dodge trucks, and the Dodge Viper with a new system known as the Jeep/Truck Engine Controller (JTEC) system. In 1998, with enhanced OBD II standards requiring certain changes, Chrysler upgraded the SBEC III system on its passenger cars and minivans to an SBEC IIIA system. In each of these systems the PCM has different pin arrangements so that an incorrect replacement PCM cannot be used inadvertently. Chrysler continued to use both the SBEC IIIA system and the JTEC system on its vehicles through the 2001 model year.

On certain 2002 model-year vehicles, Chrysler introduced a new, state-of-the-art engine and transmission control system known as the Next Generation Controller, or NGC system. This NGC PCM not only controls engine performance but also replaces the transmission control module (TCM) that had been used alongside the PCM on previous systems. As of the 2005 model year, the NGC system has replaced all SBEC IIIA and JTEC systems.

Features

Automatic Shutdown Relay. The ignition switch energizes the ASD relay when it is in the run position. The power module energizes the ASD coil by grounding its return circuit, and the ASD relay powers the electric fuel pump, the ignition coil, and the injector(s).

The fuel pump has its own independent ground and turns on immediately. The ignition coil and injectors get power from battery positive, but no current flows through their circuits until the power module grounds their activation circuits. From 1985 through 1987 the ASD relay was internal to the power module. In 1984 vehicles and after 1987, it is a separate relay, outside the power module (Figure 15–6). Mounting it outside saves module space and improves module reliability by removing the heat it generates.

Beginning in 1990, the ASD relay was also used to provide power for the heating element of the heated oxygen sensor(s) on the vehicle. Beginning in 1996, SBEC systems began using a dedicated

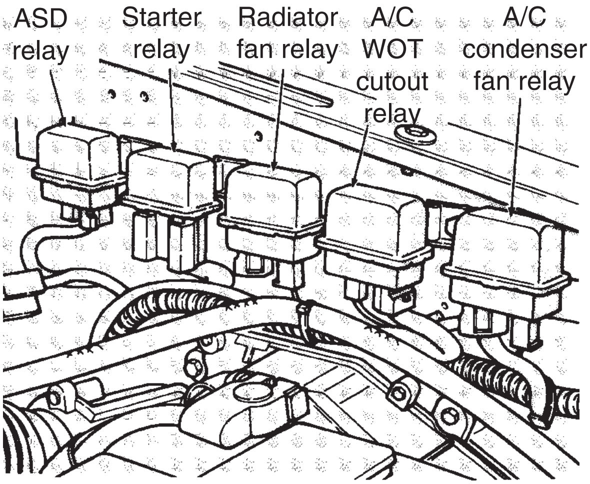


Figure 15–6 Typical location, ASD relay. (Courtesy of Chrysler Corp.)

fuel pump relay to provide power for the fuel pump. But the system retained the ASD relay, which now provides power for the fuel injectors, the ignition coil primary winding, the heated oxygen sensor(s), and the alternator field windings. Both relays are de-energized if the tach reference signal is lost.

Adaptive Memory. **Adaptive memory** is the ability of an engine control computer to assess the success of its actuator and sensor signals and to modify its internal calculations to correct them if the desired result is not achieved. The PCM can modify some of its programmed calibrations ("maps") for fuel metering to compensate for production tolerance variations and changes in barometric pressure or vehicle altitude.

There are limits to the range of adjustment available to the adaptive memory capacity. Sometimes mechanical problems—a collapsed exhaust system, a burnt valve—throw the engine performance so far off that no countermeasure available to the computer can correct for it.

Operating Modes

Starting. When the starter cranks the engine, double injector pulses occur to richen the intake mixture. The single-point injector on the nonturbocharged engines normally pulses twice per revolution; the multipoint injectors were initially designed to pulse in pairs, each pair spraying fuel once each revolution. The double-pulsing during crank occurs only for a programmed time interval to avoid flooding. At first, coolant temperature alone determines the pulse width. Once the engine starts, the PCM provides fuel enrichment depending on coolant temperature and manifold pressure. The start-up enrichment "decays" to base enrichment over a programmed time interval. Once the coolant reaches the closed-loop criterion temperature, of course, the feedback system controls mixture.

Primer Function. As soon as a driver turns the ignition on for the 3.0-L engine, all six injectors pulse fuel into the intake ports. This improves starting and is done regardless of coolant temperature, though if the coolant is warm, less fuel will spray. If the engine is cold, relatively more fuel is sprayed.

Open Loop. Open loop—when the oxygen sensor does not determine fuel injection pulse width—occurs when:

- The coolant is below a criterion temperature.
- The oxygen sensor is below operating temperature (approximately 600°F/315°C).
- The vehicle is at wide-open throttle (WOT) or under similar high acceleration or load.
- The turbocharger boost on the multipoint system reaches 1 PSI or more.
- An engine with the single-point injector is idling.
- There is a major sensor or actuator malfunction preventing feedback mixture control.

Closed Loop. Each Chrysler system will go into closed loop only if:

- The coolant has reached the criterion temperature.
- The oxygen sensor produces a usable signal.
- A vehicle-specific time has passed since start-up.

Limp-In Mode. The PCM's self-diagnostics circuits include the capability to monitor incoming signals from the most important sensors. If one of them sends a signal out of the expected range or no signal at all, the PCM considers the sensor inoperative and shifts the engine management system into **limp-in mode.** In this mode, the PCM substitutes a probable value for that of the failed sensor, sets a fault code, and turns on the malfunction indicator light (MIL), formerly known as the power loss lamp, on the dashboard. Obviously, the PCM cannot substitute for the distributor's Hall effect sensor signal; the engine just stops. But it can substitute plausible values for coolant temperature or manifold absolute pressure (MAP) sensors.

In limp-in mode, the engine will not develop full power nor operate with full efficiency, but it can still run. The following are the sensors whose failure can trigger limp-in mode:

- Manifold absolute pressure (MAP) sensor. The computer can create a simulated value from the inputs from the throttle position sensor and the engine speed.
- Throttle position sensor (TPS). The computer uses the MAP sensor signal to create a substitute value.
- Engine coolant temperature (ECT) sensor. The computer uses the charge temperature (intake manifold fuel/air mixture temperature) sensor signal as a substitute.
- Intake air temperature (IAT) sensor. The computer can usually manage engine performance without this information.

If the distributor reference signal stops, so does the engine, since there is then no way to time ignition spark.

Diagnostic & Service Tip

Certain mechanical problems can throw a system out of closed loop repeatedly. Suppose a car develops a series of bad oxygen sensors in a relatively short time. An experienced technician will check for causes external to the system, too. This particular problem often comes when a head gasket is starting to fail and seeps coolant into the combustion chamber or exhaust. The silicone in the coolant forms a super-thin, impermeable layer on the exhaust surface of the sensor, "poisoning" it. Less frequently, coolant silicone from a burst hose or some other contaminant will get into the atmospheric side of the sensor. More rarely, silicone poisoning occurs when a technician uses older silicone-based gasket sealers.

INPUTS

Manifold Absolute Pressure Sensor

The MAP sensor is a piezoresistive pressure sensor. A piezoresistive diaphragm changes its electrical resistance in response to a slight flexing caused by changes in pressure. The PCM uses its signal as a barometric pressure sensor during periods of key on/engine off or during certain other conditions on a few models as explained in the "Outputs" section of this chapter (Figure 15–7).

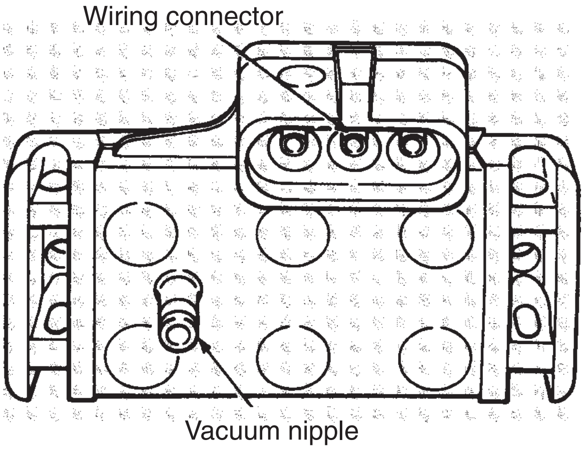


Figure 15–7 MAP sensor. (Courtesy of Chrysler Corp.)

The MAP sensor is usually located on the logic module in the two-module system.

The technician should understand clearly what manifold absolute pressure is. Formerly, the term *intake manifold vacuum* was used, but that can be misleading (particularly after the widespread introduction of turbocharged cars). The manifold absolute pressure is the actual pressure of the air in the intake manifold. Often, of course, it is lower than ambient pressure, but it is still air pressure. If a turbocharger or supercharger increases the pressure above ambient pressure, it is still manifold absolute pressure. This value corresponds very closely to engine load.

Some earlier vehicles had a small bleed hole in the vacuum line to the MAP sensor to prevent condensation from collecting in the line. These MAP sensors are calibrated to allow for the vacuum leak.

Baro Read Solenoid

In 1985, Chrysler added a baro read solenoid that allowed the PCM to use the MAP sensor to update its barometric pressure values without having to wait for a restart of the engine. If the PCM energizes the baro read solenoid, then the MAP sensor is isolated from the manifold vacuum/pressure signal and is simultaneously vented to the atmosphere.

Diagnostic & Service Tip

The early MAP sensor arrangement had two problems frequently seen in repair bays. In colder climates in winter, the system would set a code and drop into limp-in mode. After the vehicle was in the work bay for a while, the problem mysteriously disappeared without repairs. What happened was this: Dirt plugged the vacuum line vent; moisture froze and plugged the line, blocking vacuum from the sensor. The computer noticed the problem and set the code. Once the car was in the heated work bay, the ice plug melted, and the sensor worked normally.

Diagnostic & Service Tip

The early system used the MAP sensor as a barometric sensor when the ignition was on but the engine off, and it retained that value in memory for the duration of that trip. However, if the trip involved a significant change of altitude—up or down a sizable mountain—the engine might run very poorly until it was shut off and restarted, with no codes set because there was no sensor or actuator circuit fault. A driver or roadside mechanic who believed that it was bad policy to shut off an engine that was still running, however poorly, would never get the engine right until the car returned to the beginning altitude or stalled or ran out of gas and stopped on its own.

Throttle Position Sensor

The TPS is a rotary potentiometer—a variable resistor—at the end of the throttle shaft on the side of the throttle body. Depending on the position of the throttle, the sensor modifies the 5-V reference signal to something less, corresponding with the throttle's current position, and it returns that signal to the computer. Engine management systems also keep track of how quickly the throttle moves, to more accurately provide acceleration enrichment when the pedal is suddenly floored or to shut off fuel if the throttle is suddenly closed at high engine speed.

Oxygen (O_2) Sensor

The early Chrysler systems used a single-wire oxygen sensor. Newer systems use a heated sensor with additional wires for an internal heater element.

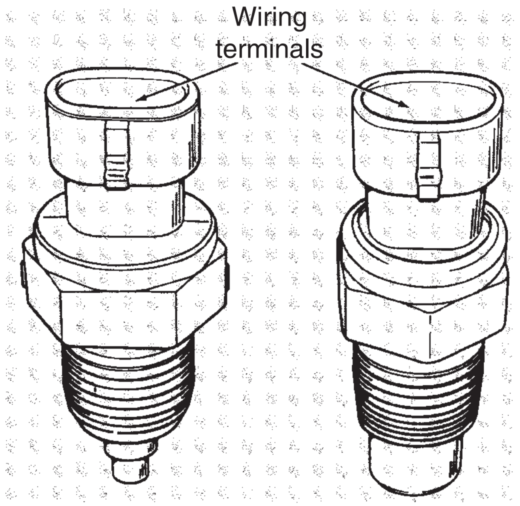


Figure 15–8 IAT and ECT sensors. (Courtesy of Chrysler Corp.)

Engine Coolant Temperature Sensor

The ECT sensor is a single-element, negative temperature coefficient (meaning the resistance goes down as the temperature goes up) thermistor screwed into the thermostat housing (Figure 15–8). As it warms up, its resistance goes down. At −4°F/−20°C its resistance is 11,000 Ω; it ranges to 800 Ω at 195°F/90.5°C, full operating temperature on these systems. Prior to OBD II standardization, the ECT sensor was known by Chrysler as a *coolant temperature sensor,* or *CTS.*

Intake Air Temperature Sensor

The IAT sensor is a single-element thermistor (again negative temperature coefficient-type) screwed into a runner of the intake manifold. It has about the same resistance range as the coolant temperature sensor and looks similar. On early models its input contributes to cold engine enrichment calculations; otherwise it serves as a backup to the ECT sensor. On later multipoint systems, its input helps to control the air/fuel mixture when cold and to boost control at all times. Prior to OBD II standardization, the IAT sensor was known by Chrysler as a charge temperature sensor or charge temp sensor.

Throttle Body Temperature Sensor

The low-pressure, single-point system does not include the charge temperature sensor but, instead, a throttle body temperature sensor to measure temperature at the throttle body (Figure 15–9). This temperature will ordinarily be very close to intake air temperature, and this signal helps calculate the mixture for hot restarts.

Range-Switching Temperature Sensor (Dual Range Temp Sensor)

To fine tune the fuel/air mixture and spark timing even further, beginning in 1992 Chrysler changed to range-switching temperature

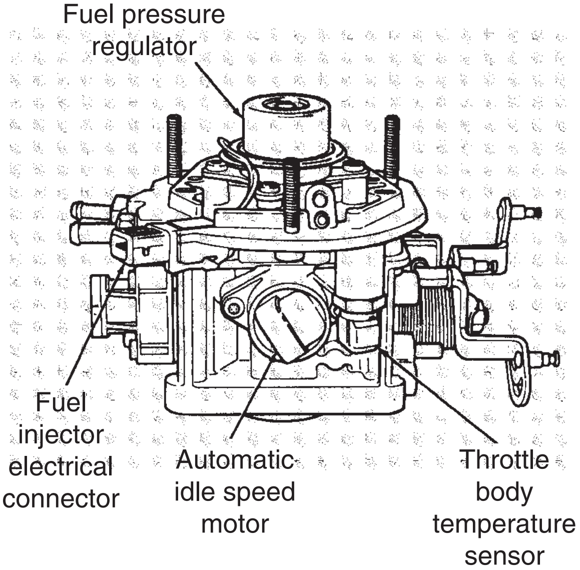

Fuel pressure regulator
Fuel injector electrical connector
Automatic idle speed motor
Throttle body temperature sensor

Figure 15–9 Low-pressure, single-point throttle body with throttle body temperature sensor. (Courtesy of Chrysler Corp.)

Temp. of	Sensor resistance	Temp. change	Resistance change	Ohm change per degree	Volt drop across sensor	
– 20°F	156,667 Ω				4.7 V	With 10,000-Ω fixed resistance
		10°	50,388 Ω	5038.8		
– 10°F	106,279 Ω				4.57 V	
40°F	25,714 Ω				3.6 V	
		10°	6,302 Ω	630.2		
50°F	19,412 Ω				3.3 V	
110°F	4,577 Ω				1.57 V	
		10°	1,244 Ω	124.4		
120°F	3,333 Ω				1.25 V	
Sensor circuit shift (909-Ω fixed resistance rather than 10,000 Ω)						
140°F	2,338 Ω				3.6 V	With 909-Ω fixed resistance
		10°	406 Ω	40.6		
150°F	1,932 Ω				3.4 V	
200°F	839 Ω				2.4 V	
		10°	125 Ω	12.5		
210°F	714 Ω				2.2 V	
240°F	435 Ω				1.62 V	
		10°	64.5 Ω	6.45		
250°F	371 Ω				1.45 V	

Figure 15–10 Temperature, resistance, and voltage drop change with dual-range temperature sensor.

sensors for coolant and air temperature (Figure 15–10).

The purpose of this change is to telescope the sensitivity of the sensor in the area of greatest importance, around operating temperature. It also accommodates the problem that the thermistor's reaction to changes in temperature is not linear—that is, there is more change in the cooler (lower) temperatures than at the upper end. Unfortunately, for engine management purposes, we are more interested in knowing about the higher temperatures in fine detail for air/fuel mixture control.

The sensor works like this: Below 125°F, there is a fixed 10,000-Ω resistor in series with the sensor's thermistor (Figure 15–11). At about 125°F, the PCM turns on a 1000-Ω resistor in parallel with the 10,000-Ω fixed unit. This toggles the resistance to 909 Ω.

This spreads out the resistance more evenly over the range the computer is seeking. Of course, it is actually measuring the voltage drop across the thermistor. This range shift means, of course, that the computer must know that the change that occurs around 125°F is not a sudden cooling of the engine but the result of the resistance switch. This "expectation" is programmed into the PCM's memory.

When the second resistor is switched into parallel, the total fixed resistance is then considerably lower than that of the thermistor. There is a wider range of voltage drop available to be monitored and greater accuracy is obtainable.

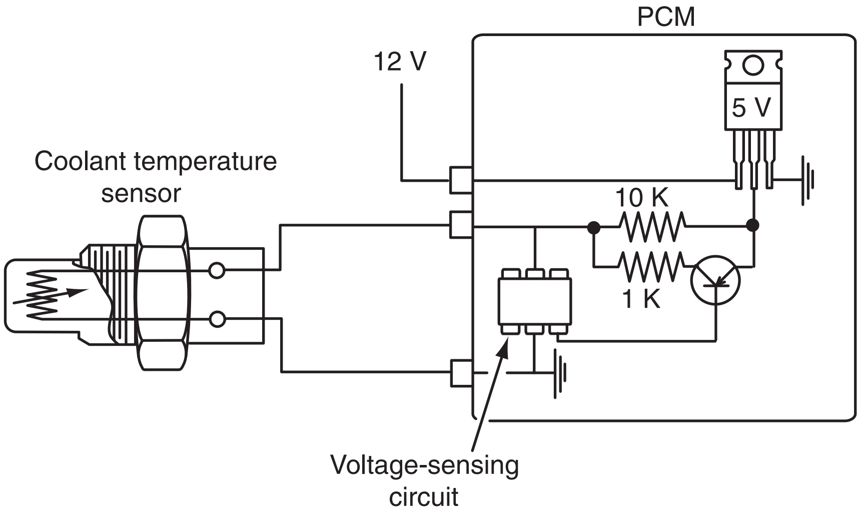


Figure 15–11 Dual-range temperature sensor electrical schematic.

TMAP Sensor

Chrysler 2.0-L, 3.2-L, and 3.5-L engines use a sensor called the TMAP (Figure 15–12). This sensor combines the functions of the IAT sensor and the MAP sensor into one component. The TMAP sensor is located at the intake manifold.

TMAP Strategy

Due to slow MAP sensor response when the driver suddenly moves the throttle, some Chrysler PCMs follow a strategy that uses the TPS signal to initially calculate MAP values as the throttle is moved, resulting in a quicker PCM response

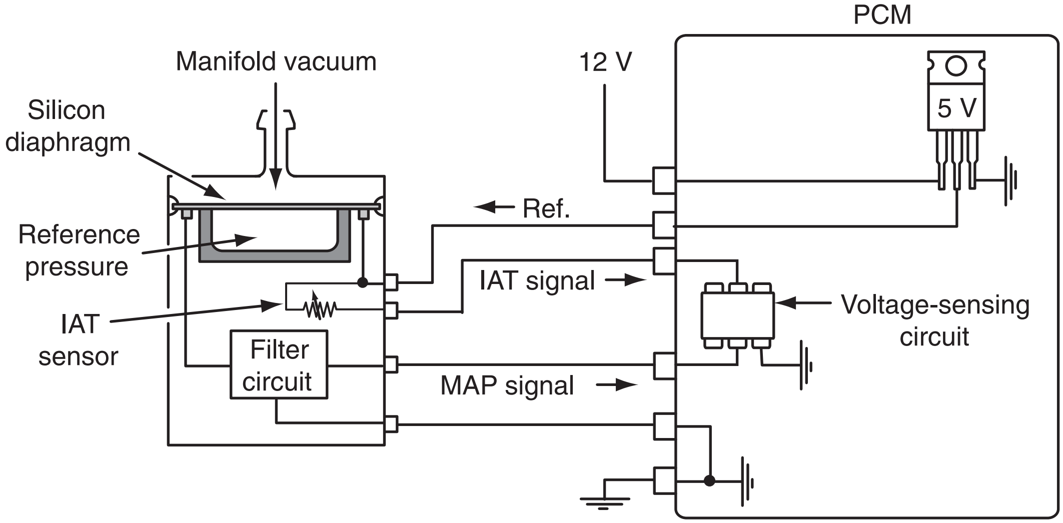


Figure 15–12 TMAP sensor electrical schematic.

to throttle movement. This strategy is referred to as the TMAP strategy; it should not be confused with the TMAP sensor.

Mass Airflow Sensor

Chrysler introduced a mass air flow (MAF) sensor on the 2001 Chrysler Sebring and Dodge Stratus, similar to the sensors that GM and Ford began using in the 1980s. Chrysler's MAF sensor is made by Mitsubishi and is called the *Mitsubishi Ultimate Karman Airflow Sensor* or MUKAS. It replaces the speed density formula for *calculating* air intake and measures air intake with a hot-wire-type sensor. It does this by measuring the cooling effect of the air's molecules on a heated wire element. This hot wire is kept heated to a certain temperature above the temperature of the ambient air entering the engine, as measured by the IAT sensor. The IAT sensor allows the MAF sensor to be indexed to ambient air temperature so that only the *quantity* of air molecules, not their temperature, affects the hot wire.

The Chrysler MAF sensor produces a square-wave variable digital frequency by grounding out a 5-V reference voltage from the PCM. The frequency at which it does this is measured by the PCM to determine measured air intake. A Hertz meter should be used to measure the resulting signal, similar to GM MAF sensors and Ford EEC IV digital MAP sensors. If the ignition is turned on, but the engine is not running, the voltage is pulled to ground and does not oscillate.

Distributor Reference Pickup

A Hall effect switch in the distributor generates the reference pickup (REF pickup) signal, from which the PCM determines engine speed and crankshaft position (CKP) (Figure 15–13). On the dual module single-point system, this same signal goes to both modules. Without the signal, the power board removes ground from the ASD relay, shutting off the ignition coil, injectors, and fuel pump. On the dual module multipoint systems, only the logic board gets the distributor reference signal, but the logic board uses it to instruct the power board when to turn on the injectors.

A Hall effect sensor has specific differences from an inductive AC voltage generator. The Hall effect pickup (sensor) generates a clean on/off signal and does not vary either in accuracy or output

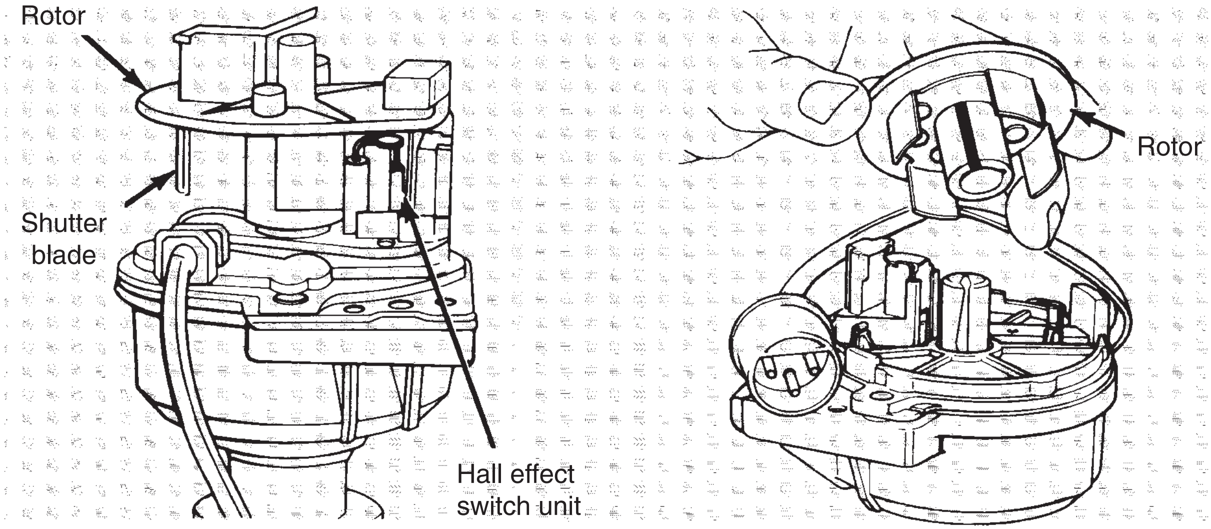


Figure 15–13 Hall effect pickups. (Courtesy of Chrysler Corp.)

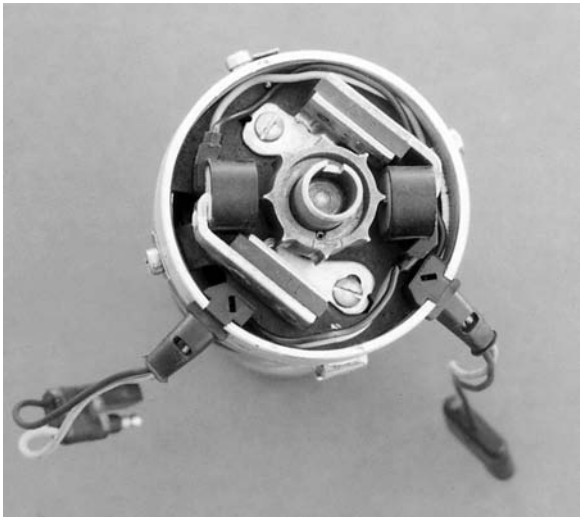


Figure 15–14 A Chrysler distributor with dual magnetic inductive pickups.

voltage with RPM. An **inductive pickup** (sensor) (Figure 15–14), on the other hand, produces an alternating current, and the point of polarity reversal is the reference point. An inductive sensor may produce very low voltage signals at low speed and very high voltage at a higher speed. It can also change position as the speed increases, because of the time required for the magnetic field to reverse. A Hall effect sensor, however, does not generate its own current. It is dependent on the reference signal sent to it; the circuit is more complex and more things can go wrong.

Distributor Sync Pickup (SYNC Pickup)

Most multipoint systems use a second Hall effect switch/sensor in the distributor, below the REF pickup (Figure 15–15). This switch has a shutter wheel with only one vane instead of four. The one vane, however, covers 180 degrees, half of the shutter wheel. The leading and trailing edges of the vane each provide a signal (on or off) to the PCM. The PCM uses the SYNC signal along with other information to calculate pulse width. The power board uses it to determine which pair of injectors (1 and 2 or 3 and 4) to turn on when the instruction from the PCM arrives.

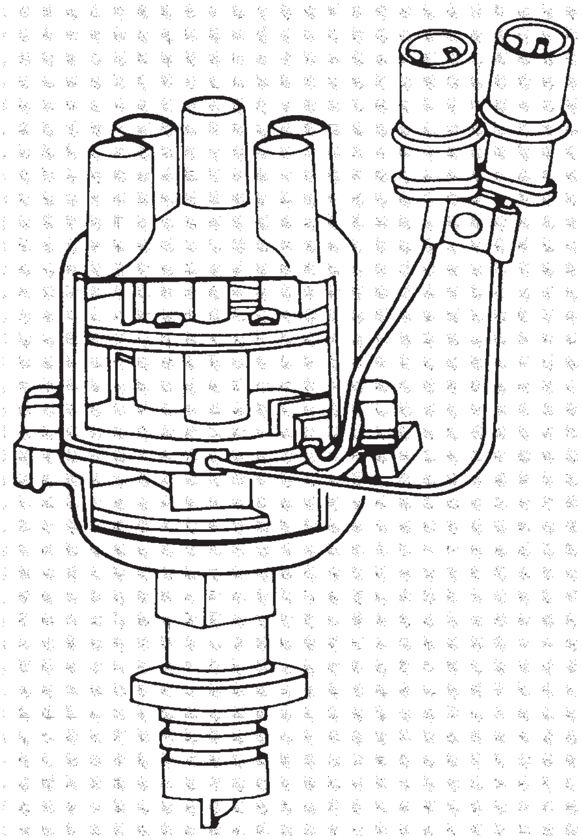


Figure 15–15 Distributor for turbocharged four-cylinder engine, with reference and sync Hall effect pickups. (Courtesy of Chrysler Corp.)

Optical Distributor. A 3.0-L V6 engine, built by Mitsubishi, appeared on some Chrysler vehicles in 1987. This was Chrysler's first naturally aspirated (non-turbocharged) engine with multipoint fuel injection.

The engine management system with this engine does not use the Hall effect distributor, but rather an optical distributor with a pair of optical sensors (Figure 15–16). A disc with two sets of slits rotates with the distributor shaft. The inner set has six slits, called "low data rate" slits. The outer set has one slit for every two degrees of

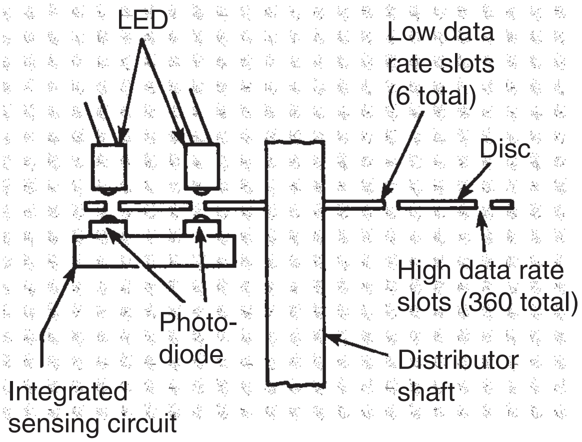

LED
Low data rate slots (6 total)
Disc
High data rate slots (360 total)
Photo-diode
Distributor shaft
Integrated sensing circuit

Figure 15–16 Optical distributor pickup.

crankshaft rotation except for one small blank spot with no slits. This section alerts the PCM where the number 1 cylinder is. The high data rate from this sensor allows the computer to track minute changes in engine speed.

Two light-emitting diodes (LEDs) are on one side of the disc, and the receptors are on the other (Figure 15–17). When one of the slits aligns with an LED, the light strikes a photodiode in the receptor, generating a small voltage applied to the base of a transistor.

We will follow the "low data rate" reference signal for the explanation, though the "high data

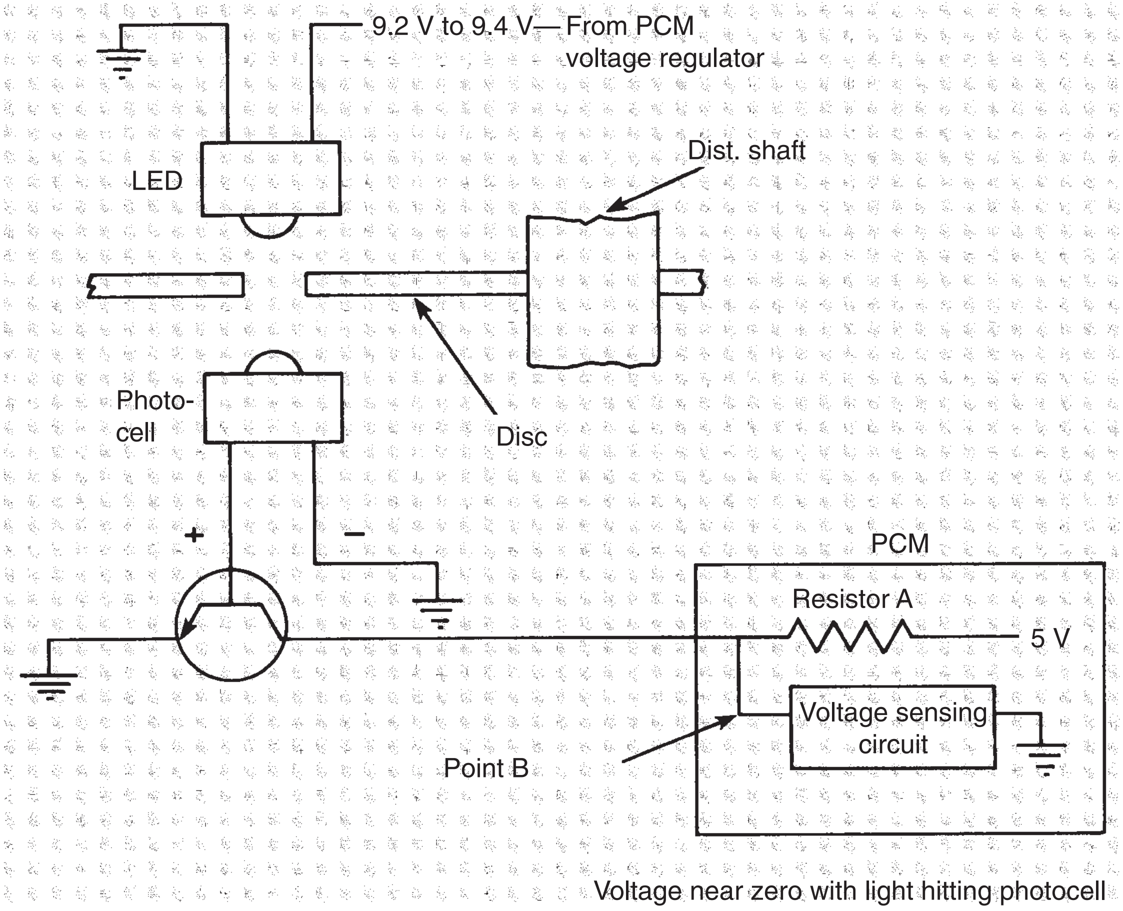

9.2 V to 9.4 V— From PCM voltage regulator
LED
Dist. shaft
Photo-cell
Disc
+
−
PCM
Resistor A
5 V
Voltage sensing circuit
Point B
Voltage near zero with light hitting photocell

Figure 15–17 Optical distributor sensor electronic schematic.

rate" circuit works similarly: The transistor acts as a grounding switch for the 5-V reference signal sent through a resistor within the PCM. When infrared light from the LED strikes the photocell, the photocell produces enough voltage to forward bias the transistor. The transistor, in turn, completes the circuit to ground and thus pulls low the voltage that the computer's voltage sensing circuit sees. When a metal slit in the distributor disc moves and blocks the light, the photocell allows the transistor to turn off. The transistor then opens the ground circuit and the voltage that is monitored by the computer's voltage sensing circuit returns to 5 V. Each time the voltage is pulled low, the PCM knows the next piston in the firing order has reached a specific position in its cycle. The high data rate sync circuit works similarly except that each signal indicates the crankshaft has rotated two degrees.

Below 1200 RPM, the PCM uses the sync signal (high data rate) to calculate spark timing and injector pulse. Above 1200 RPM, it uses the reference signal (low data rate). The reason for the switch (besides the easier task of monitoring the lower data rate at higher engine speeds) is that there are significant changes in engine speed at each power stroke, but slight differences in compression ratio, spark plug condition, and fuel atomization mean different changes for each cylinder. The high data rate signal allows the PCM to monitor these changes and adjust timing and injection pulse accordingly. At higher engine speeds, there is much less variation in RPM between different cylinders' power strokes, so such detailed adjustments are not necessary.

Direct Ignition System. In 1990, Chrysler introduced its own 3.3-L, 60-degree V6 for some of its passenger cars and vans (Figure 15–18). This engine uses a distributorless, **direct ignition system** (DIS) similar to the General Motors and Ford distributorless systems. The idea of using one coil to fire a pair of plugs—one coil for every two cylinders—goes back to motorcycles, in which high RPM limited available dwell time to build up the coil's field and in which space for the coils was even more limited than on cars. This system is often called a **waste spark ignition** system. Both plugs on the same coil fire simultaneously: one at the end of its compression stroke just before the power stroke, the other at the end of its exhaust stroke. Because of the low resistance in the exhaust stroke combustion chamber, the "waste spark" requires less voltage than the active one.

The electrical difference between a waste spark distributorless DIS and a conventional setup is that the ignition secondary (high-voltage) windings are not directly grounded. Instead, one plug gets a negative polarity spark and the other a positive polarity. Of course, from the point of view of the air/fuel mixture, the polarity of the spark does not matter: Any hot spark of either polarity ignites the air/fuel mixture.

The Chrysler DIS, like the GM and Ford systems, uses Hall effect crankshaft position (CKP) and camshaft position (CMP) sensors, an ignition module, and a coil pack with a coil for every 360-degree pair of cylinders (those with exactly alternating power strokes). The coil pack bolts over the ignition module.

These Hall effect CKP and CMP sensors are of a unique design in that the body of the sensor contains a permanent magnet near the front end and a Hall effect switch near the back end (Figure 15–19). As iron (metal) is passed near the front end, the magnet's magnetic field is enhanced enough to encompass the Hall effect crystal behind it, causing the Hall effect switch to turn on. When the iron moves away from the Hall effect switch, the magnet's magnetic field is weakened enough that it no longer encompasses the Hall effect switch behind it, causing the Hall effect switch to turn off.

The CMP sensor mounts on the timing cover and triggers off slots on the camshaft timing gear (Figure 15–20). The slots on the timing gear are coded so that signals from the sensor identify which pair of companion cylinders the ignition module should fire next in response to the computer's spark timing command. This signal

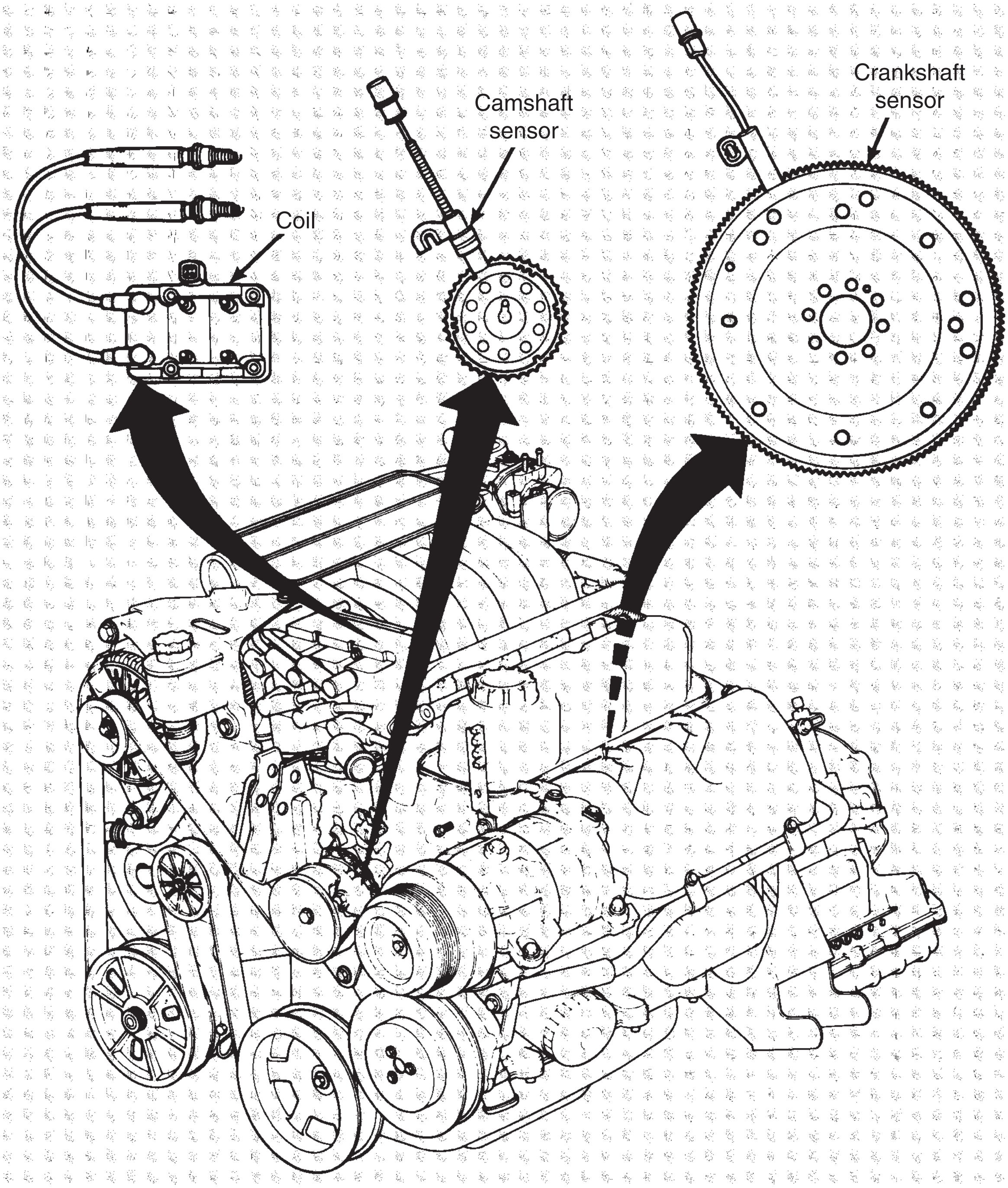


Figure 15–18 3.3-L DIS with camshaft and CKP sensors. (Courtesy of Chrysler Corp.)

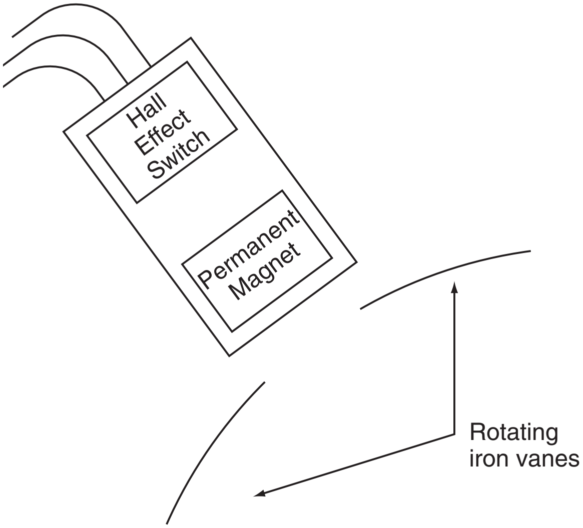


Figure 15–19 Chrysler Hall effect sensor used with the DIS system.

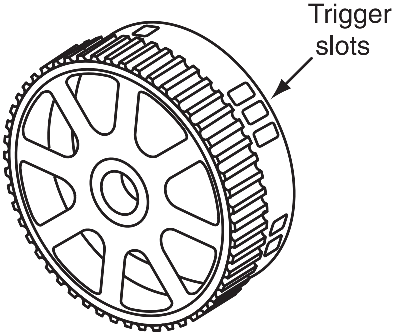


Figure 15–20 Six-cylinder CMP trigger. (Courtesy of Chrysler Corp.)

can also determine which injector the computer pulses next. Because the camshaft sensor can identify individual cylinders (unlike the crankshaft sensor), the computer can use its signal to begin firing spark plugs and pulsing fuel injectors within the first crankshaft rotation.

The crankshaft sensor mounts on the bell housing and triggers off slots on the torque converter drive plate (Figure 15–21). There are four slots per pair of companion cylinders.

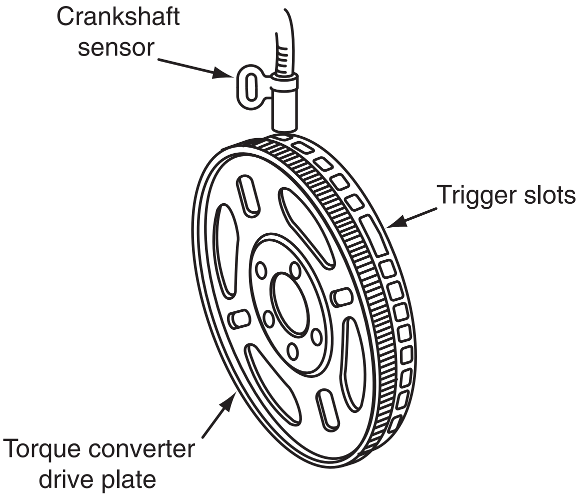


Figure 15–21 CKP trigger. (Courtesy of Chrysler Corp.)

The computer uses these signals to determine CKP and engine speed. It then uses this information to determine ignition timing, injector timing, and injector pulse width.

Figure 15–22 shows the waveforms generated by Chrysler's typical Hall effect CMP and CKP sensors.

Vehicle Speed Sensor

The speed sensor is a simple on/off switch that cycles eight times per speedometer cable rotation. The computer sends it a steady 5-V reference signal that it interrupts at a frequency corresponding to transaxle output shaft speed. The vehicle speed sensor (VSS) mounts to the transaxle at the base of the speedometer cable (Figure 15–23).

In 1992 Chrysler began using a Hall effect VSS (Figure 15–24). To power up, this sensor receives power and ground, then delivers a digital square wave to the PCM at a rate of 8000 pulses per mile. The power supply is delivered to the VSS from the PCM over the same circuit that carries power to the CKP and CMP Hall effect sensors: 8 V on early models and 5 V on newer versions.

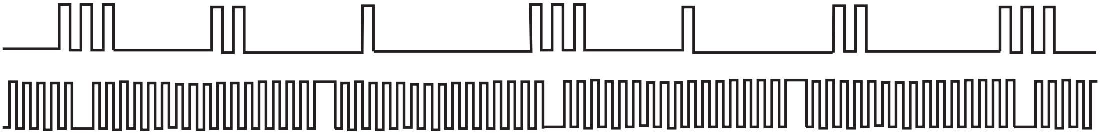


Figure 15–22 Typical waveforms generated by Chrysler's CMP and CKP Hall effect sensors. (Courtesy of Chrysler Corp.)

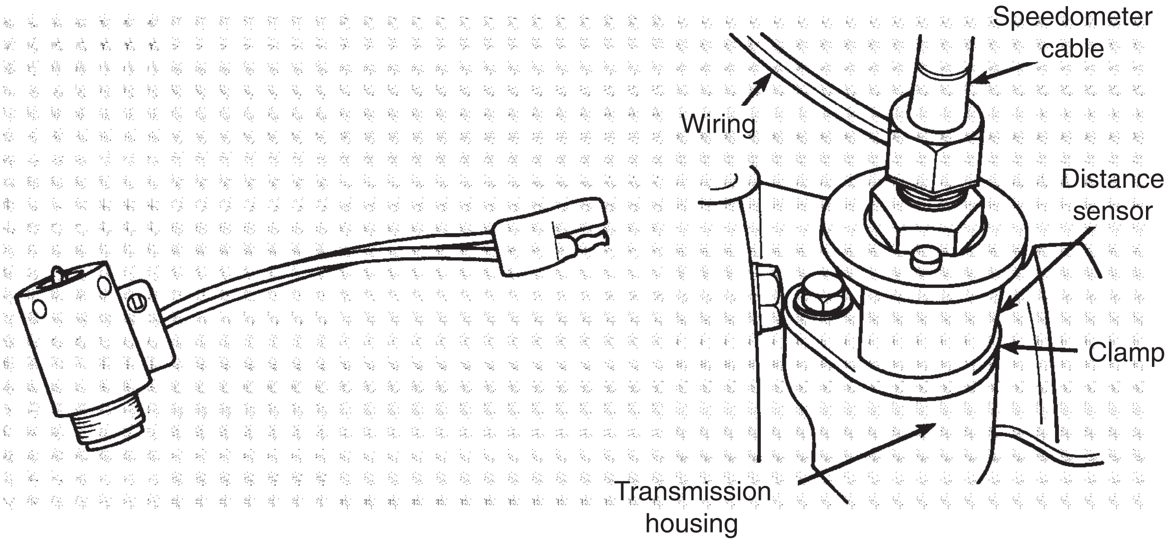


Figure 15–23 Vehicle speed sensor. (Courtesy of Chrysler Corp.)

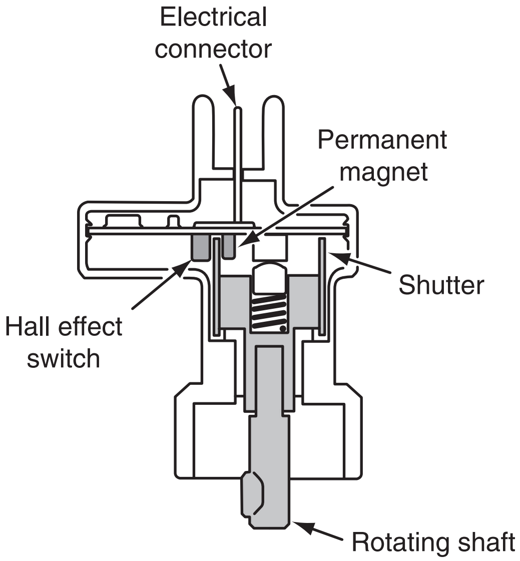


Figure 15–24 Hall effect VSS.

Therefore, if the VSS were to short its power circuit to ground internally, the engine would not start due to the simultaneous loss of power at the CKP and CMP sensors.

Newer Chrysler vehicles also use inductive permanent magnet VSSs that monitor iron teeth and notches on the output shaft of the transaxle, producing AC voltage pulses that are sent to the PCM. As a result, depending on the application, newer Chrysler products may use either a Hall effect VSS or an inductive permanent magnet VSS.

Also, prior to OBD II standardization, Chrysler referred to the VSS as a "distance sensor" due to the fact that the *number* of pulses produced only represents distance. The PCM must then combine the number of these pulses with time by looking at the *frequency* of the pulses in order to calculate vehicle speed.

Detonation (Knock) Sensor

The Chrysler knock sensor is of the piezoelectric type; it is mounted on the intake manifold. When excited by vibrations typical of detonation, it sends a true alternating current signal to the computer. The PCM then begins countermeasures, which reduce spark advance by individual cylinders and/or reduce turbocharger boost.

Chrysler 3.2-L and 3.5-L engines have changed from dual knock sensors to a single broadband knock sensor. This new sensor has a broader operating range of 5 KHz to 20 KHz. Unlike the previous single-wire knock sensor, the new unit uses two wires that provide the single broadband knock sensor with its own high ground. This means that the sensor no longer shares the common ground of all the other electrical circuits in the vehicle. The two sensor wires are twisted to improve the shield from unwanted signals (Figure 15–25).

Battery Temperature Sensor

A thermistor in the PCM, adjacent to the battery, signals the battery's ambient temperature to the computer. The computer then uses this information to regulate alternator output and battery charging rate.

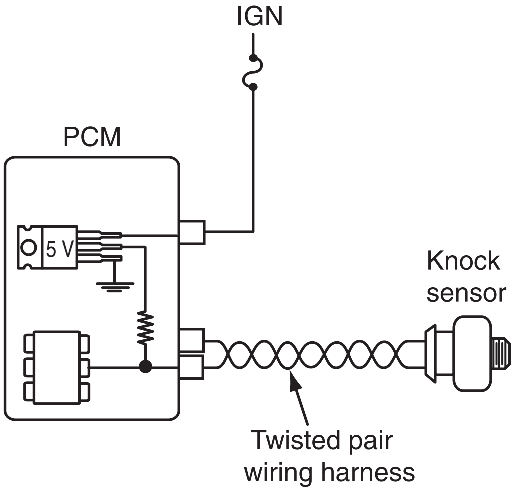


Figure 15–25 Knock sensor circuit.

Charging Circuit Voltage

The PCM senses charging system voltage by monitoring the fuel pump power feed circuit; it regulates alternator output accordingly. As we learned in the preceding paragraph, it also factors in the battery temperature to determine the proper charging voltage.

Switch Inputs

Park/Neutral Switch. The park/neutral (P/N) switch tells the PCM whether the transmission is in gear. Its input influences idle speed. Normal idle spark advance is canceled when the transmission is in neutral or park.

Electric Backlite (Heated Rear Window). When the heated rear window switch is on, the PCM increases the idle speed to compensate for the additional load the heating current places on the alternator.

Brake Switch. Should the throttle position sensor (TPS)/switch fail, the computer looks to the brake light switch as a signal that the throttle is closed.

Air Conditioning (A/C). Whenever the A/C is on, the A/C control circuit sends the PCM computer a signal. The PCM then increases idle speed to compensate for the additional compressor load.

Air-Conditioning Clutch. When the A/C system cycles the compressor clutch on and off at idle, the A/C clutch switch provides a signal for the computer to adjust the idle speed and compensate for variations in load. Later models combine both air-conditioning inputs into one signal.

Battery. One terminal of the PCM gets power directly from the battery to sustain power in the keep-alive memory (KAM) when the ignition is off.

OUTPUTS

Injector/Injectors

Figures 15–26 and 15–27 show the low- and high-pressure fuel injectors used in the single-point injection systems. Each type is a solenoid-operated device.

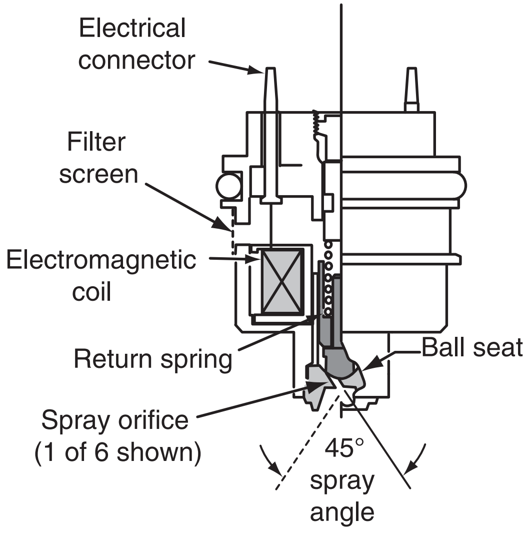


Figure 15–26 Low-pressure fuel injector.

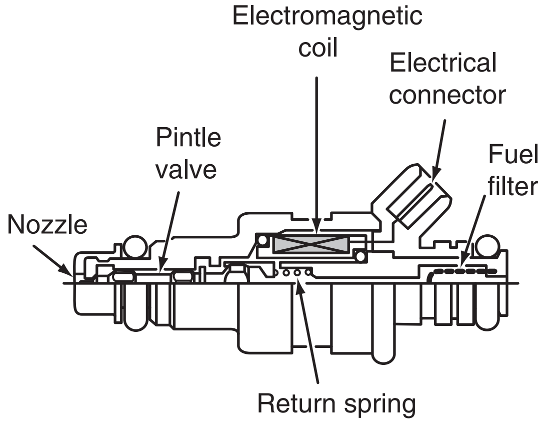


Figure 15–27 Typical high-pressure fuel injector.

In normal operation, the single-point injector pulses fuel twice for each engine revolution. The early multipoint fuel injection systems on four-cylinder engines pulsed one pair of injectors during the first revolution of a full cycle and the other pair during the second revolution. As explained before, this injection schedule was doubled during cranking.

The 3.0-L and 3.3-L V6 engines pulse injectors in sequential pairs. In each case, the PCM calculates the pulse width based on input signals from the following:

- ECT
- MAP
- RPM
- TPS
- oxygen sensor—in closed loop
- IAT—during cold enrichment
- VSS—during deceleration
- fuel enrichment and enleanment factors programmed into the PCM

In contrast to the more common wiring practice, the 1984–1987 Chrysler single-point systems have a fixed constant ground. The power module controls injection by switching power on and off (positive side switching). Beginning with the 1987 model year, the single-point system used ground-side switching, making it compatible with the multipoint systems.

Modern Chrysler fuel injection systems employ **sequential fuel injection,** a system in which each injector is pulsed individually in the engine's firing order. Not only does this design use an individual terminal of the PCM to operate each injector, but the PCM now needs to know TDC compression information for each cylinder. This information is taken from a CMP sensor or from the pickup of a distributor geared into the camshaft.

Electric Fuel Pump

A permanent magnet-type direct current electric motor drives the vane-type fuel pump, both of which are submerged in fuel at the bottom of the fuel tank. One check valve functions as a pressure relief valve; the other, in the outlet port, prevents fuel from running in either direction when the pump is off. This keeps the line full of pressurized fuel when the engine is off, reducing the potential for fuel volatility problems.

With the ignition switch on, the PCM grounds the fuel pump relay, powering the fuel pump. Unless there is a distributor reference signal within 2 seconds, the relay will lose its ground and shut off the fuel pump. Once shut off, the relay stays off until the distributor reference signal arrives at the computer or the key is cycled off and on again.

A few vehicles, such as the Shelby GLH turbocharged Omnis, use two fuel pumps, one in the tank and another near the engine. As these vehicles sometimes use more fuel, they are more subject to vapor lock. The tandem electric pumps reduce that possibility.

Fuel Pressure Regulator. To make air/fuel mixture calculations possible, the fuel injection system uses a fuel pressure regulator to keep the difference between the fuel rail and the intake manifold constant (Figure 15–28). This is often described as a "pressure differential across the injector." The amount of fuel will correspond closely to the pulse width, with no allowances needed for pressure differences.

The different systems use different pressures and different (though similar) pressure regulators. The pre-1986 single-point system maintains a fuel pressure difference of 36 PSI; the later low-pressure system maintains a difference of 14.5 PSI. The multipoint systems maintain a difference of 55 PSI. Fuel rail pressure on a Chrysler multipoint system can vary from 42 to 62 PSI.

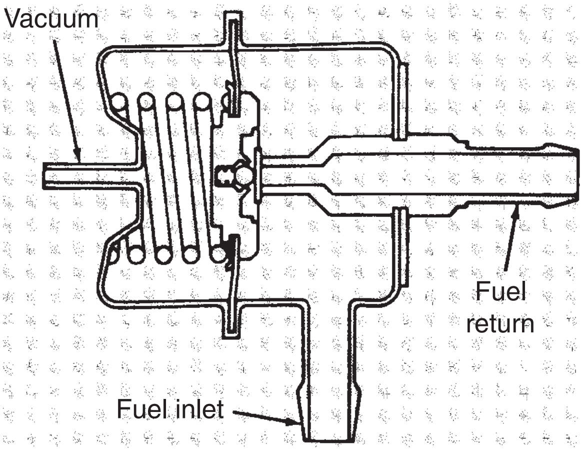


Figure 15–28 Fuel pressure regulator, multipoint turbocharger system. (Courtesy of Chrysler Corp.)

On the 3.0-L engine, the fuel pressure was raised to 46 PSI to avoid vapor lock problems during hot restarts.

Returnless Fuel System

By 1996 Chrysler fuel injection systems had changed further in two specific ways: First, fuel pressure is now held constant at approximately 49 PSI by a mechanical regulator independent of the PCM and of intake manifold vacuum. Second, the fuel injection plumbing is one way: There is no return line.

Traditionally, the fuel pressure regulator has been located on the fuel rail or return line. Fuel in excess of engine requirements is returned to the fuel tank through a return line. Returned excess fuel may return the heat it absorbed while it was in the hot engine compartment. In an effort to reduce evaporative emissions from the fuel tank, many Chrysler engines will use a returnless fuel system. The fuel pressure regulator is located on top of the fuel pump module inside the fuel tank. Fuel that leaves the fuel tank will not be returned; excess fuel is simply dumped back into the tank (Figure 15–29).

Semi-Returnless Fuel System

Based on the same concept as a returnless fuel system, a semi-returnless fuel system locates the fuel pressure regulator inside the fuel filter. The filter has three lines: a pressure line from the fuel tank, a pressure line to the fuel rail in the engine compartment, and a return fuel line that goes back to the fuel tank. The return line from the fuel filter is typically between two and four feet long but still serves to reduce the transport of engine compartment heat back to the fuel tank.

In both forms of returnless systems, the fuel rail pressure is held constant. This means that under light engine load, when there is a larger pressure differential across the fuel injectors (high vacuum/low pressure in the intake manifold), the PCM must dramatically reduce the injectors' pulse

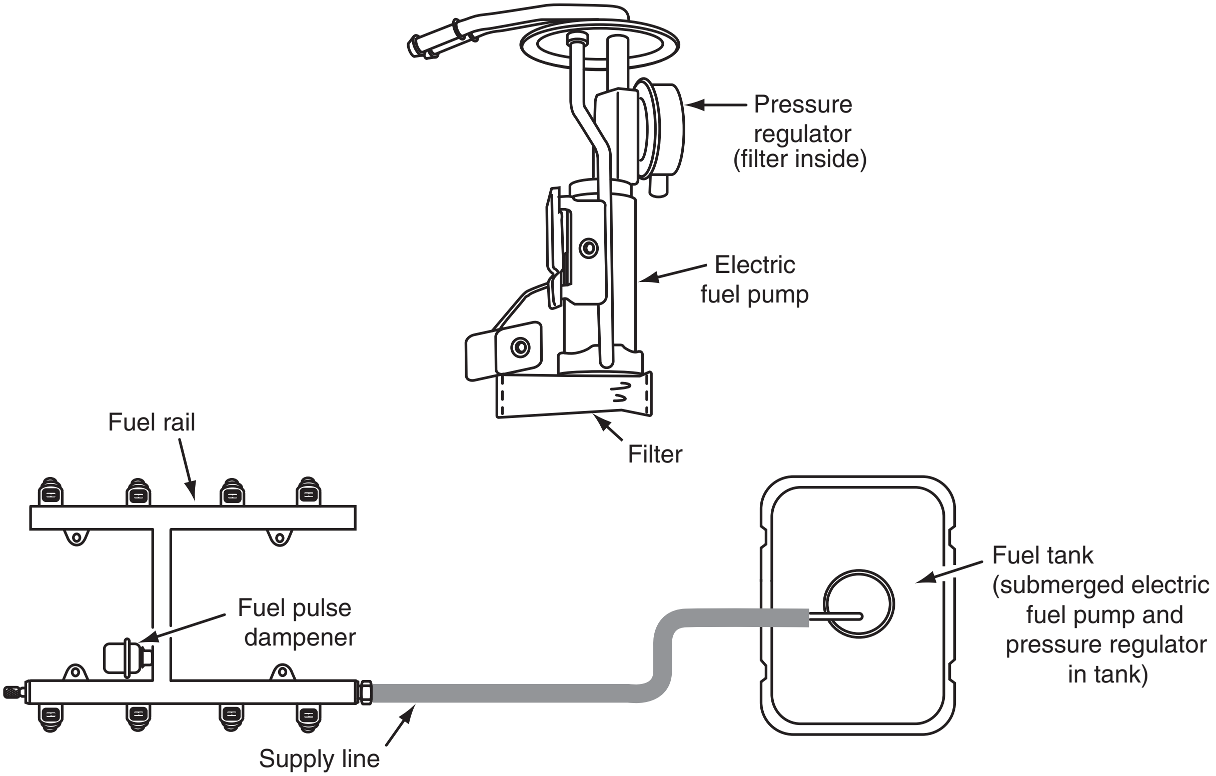

Pressure regulator (filter inside)
Electric fuel pump
Filter
Fuel rail
Fuel pulse dampener
Fuel tank (submerged electric fuel pump and pressure regulator in tank)
Supply line

Figure 15–29 Returnless fuel system/tank unit.

width. Under high engine load, when there is a small pressure differential across the fuel injectors (low vacuum/high pressure in the intake manifold), the PCM must dramatically increase the injectors' pulse width. Ultimately, the PCM must calculate the pressure differential across the fuel injectors to reliably provide the proper pulse width.

Automatic Idle Speed Motor

The automatic idle speed (AIS) motor was originally a reversible electric motor (Figure 15–30). The PCM controls it based on information from the:

- TPS
- ECT
- VSS
- P/N switch
- brake switch

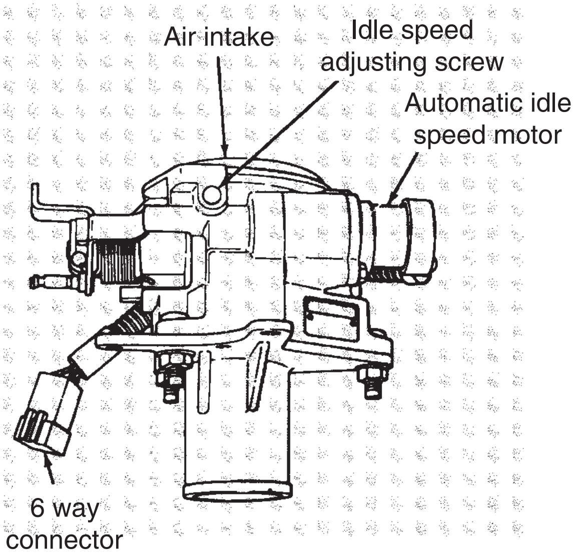


Figure 15–30 Multipoint throttle body showing AIS motor. (Courtesy of Chrysler Corp.)

The AIS motor moves its valve to control bypass air around the throttle plate in the throttle body. Even with the valve in its closed position, enough air gets past the throttle plate and through the throttle body to keep the engine idling at low speed with no load. The PCM directs the AIS motor to set the valve at different positions for different operating conditions. When the vehicle is decelerating, the valve opens to prevent engine stall and to prevent condensation of fuel on the intake port walls, as well as possible backfire.

The original DC motor was quickly replaced with a stepper motor version of the AIS actuator. This actuator moves a pintle valve to control throttle bypass air. The AIS stepper motor contains two windings that connect to the PCM with four wires. The PCM has the ability to apply current to the two windings in sequence; it also has the ability to reverse polarity to each winding as necessary. The PCM can move the AIS stepper motor through a total of 255 steps, from fully closed to fully open, to control idle speed. The stepper motor rotates a precise amount for each pulse that the computer sends it, so by tracking the number of pulses, the PCM knows the exact position of the air bypass valve. This provides the PCM with increased precision in controlling idle speed.

Automatic Idle Speed Solenoid Valve

The AIS solenoid valve (identified as an actuator with only two wires) replaces the AIS stepper motor. It is a normally closed solenoid that is operated by the PCM on a rapid pulse-width modulated (PWM) signal to control throttle bypass air. The frequency of the signal is controlled by the PCM, varying from around 1500 Hz to around 2500 Hz. At this extremely high cycling rate, the solenoid will not open and close this many times per second. Rather, the on-time of the signal causes the solenoid's iron core (with the valve attached) to *float* at a designated point between fully closed and fully open. Ultimately, this high frequency PWM signal determines the amount of atmospheric air that bypasses the throttle plates.

Ignition Timing

The PCM calculates ignition timing from information reported by:

- the coolant temperature sensor
- the distributor reference pulse (CKP/CMP sensors)
- the manifold absolute pressure (MAP) sensor
- the barometric pressure (start-up MAP reading)

At warm idle, the PCM first uses spark advance manipulation to control normal idle speed fluctuations. This action is referred to by Chrysler as *active timing.* If a specific amount of spark timing change does not put the idle speed at the design RPM, the PCM will use the AIS motor to change the amount of air entering the engine at idle.

Beginning in 1985, the multipoint system included a *baro read* (ambient barometric pressure) solenoid that the PCM used to briefly vent the vacuum line to the MAP sensor. During the time the line is vented, the MAP sensor reads ambient barometric pressure. The computer can then update this reading as often as every 30 seconds, if needed, though it is very unusual for barometric

Diagnostic & Service Tip

These changes have implications for caution on the part of service technicians. Make sure you relieve the fuel pressure before opening any part of the fuel system. The higher pressure can spray more fuel farther and harder. Also, it may be necessary to remove the fuel filler cap when working on the fuel system. The pressure it retains can be enough to push fuel through the lines, with a potential fire risk should a line be open. Keep in mind that should the system be in any actuation test mode that energizes the ASD relay, there will be full fuel delivery for as long as 5 minutes. This could potentially pump a relatively large amount of fuel.

pressure or altitude to change that quickly. This vent cycle occurs at least once each time the throttle closes and engine speed is below a certain RPM. Vehicles with a turbocharger must monitor and control ignition timing very precisely, and barometric pressure significantly affects allowable spark advance.

Ignition Coils

Chrysler vehicles use one of three ignition coil designs: single coil, DIS coil packs, and coil-on-plug (COP).

Single Coil. The single coil is used with a distributor to distribute the spark to all cylinders. This is known as distributor ignition (DI). Chrysler DI systems may either use AC inductive, optical, or Hall effect pickups within the distributor, as described in the "Inputs" portion of this chapter.

DIS Coil Packs. Many modern Chrysler applications use EI systems—that is, systems that do not use a distributor to mechanically distribute spark but, instead, use multiple coils and distribute spark *electronically* in that the PCM electronically chooses which coil to fire. Chrysler uses two versions of EI systems: waste spark and COP. The waste spark system uses multiple coils, all formed into one component called a *DIS coil pack.* Each coil within the coil pack is connected to (and fires) the spark plugs on two companion cylinders, one near the end of its compression stroke and the other near the end of its exhaust stroke. This system is known as the direct ignition system (DIS). The Hall effect CMP and CKP sensors used with this system are described in more detail in the "Inputs" portion of this chapter.

Coil-on-Plug. Chrysler 2.7-L, 3.2-L, and 3.5-L engines use a COP ignition system (Figure 15–31). The COP EI system uses the same Hall effect CMP and CKP sensors as the DIS EI system does; these are described in further detail in the "Inputs" portion of this chapter. Using one ignition coil for each cylinder and installing it on top of the spark plug eliminates secondary ignition wiring, thereby reducing the potential for the ignition system to induce voltages into nearby circuits.

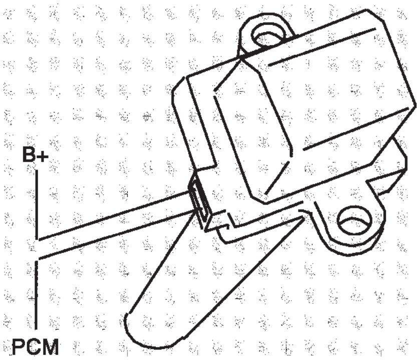


Figure 15–31 Coil-on-plug.

In this system, battery voltage is fed directly to each ignition coil. The PCM controls the ground side of each coil. The primary winding of the coil has low impedance with a resistance of 0.5 Ω. This low resistance provides quicker magnetic saturation of the coil. However, it also provides current much higher than that normally used in a computer-controlled circuit. To prevent damage to the ignition coil primary winding or to the PCM's controlling circuitry, the PCM incorporates a current-limiting strategy. When engine temperature is below 176°F, the PCM limits primary current flow to 7.7 to 9.0 amp. When engine temperature is above 176°F, the PCM limits primary current flow to only 6.0 to 6.8 amp.

Dodge Hemi Ignition System. Another interesting ignition coil design is used on the new Dodge Hemi V8 engines—the 5.7-L and 6.1-L. (Interestingly enough, the 5.7-L, which equates to 345 in.^{3}, puts out 375 ft.-lbs of torque at 4400 RPM and 345 HP at 5600 RPM—about 1 hp/in.^{3}, as did the original Chrysler Hemi V8 engines. These figures do vary slightly depending upon the application.) These engines use a waste spark system in the secondary ignition system—one ignition coil for two spark plugs. However, the V8 Hemi engines use eight ignition coils for their eight cylinders. This is because each cylinder has 2 spark plugs, for a total of 16 spark plugs.

A standard waste spark ignition coil is wired to two spark plugs on companion (opposite) cylinders by way of two secondary plug wires (Figure 15–32A). Certain applications eliminate

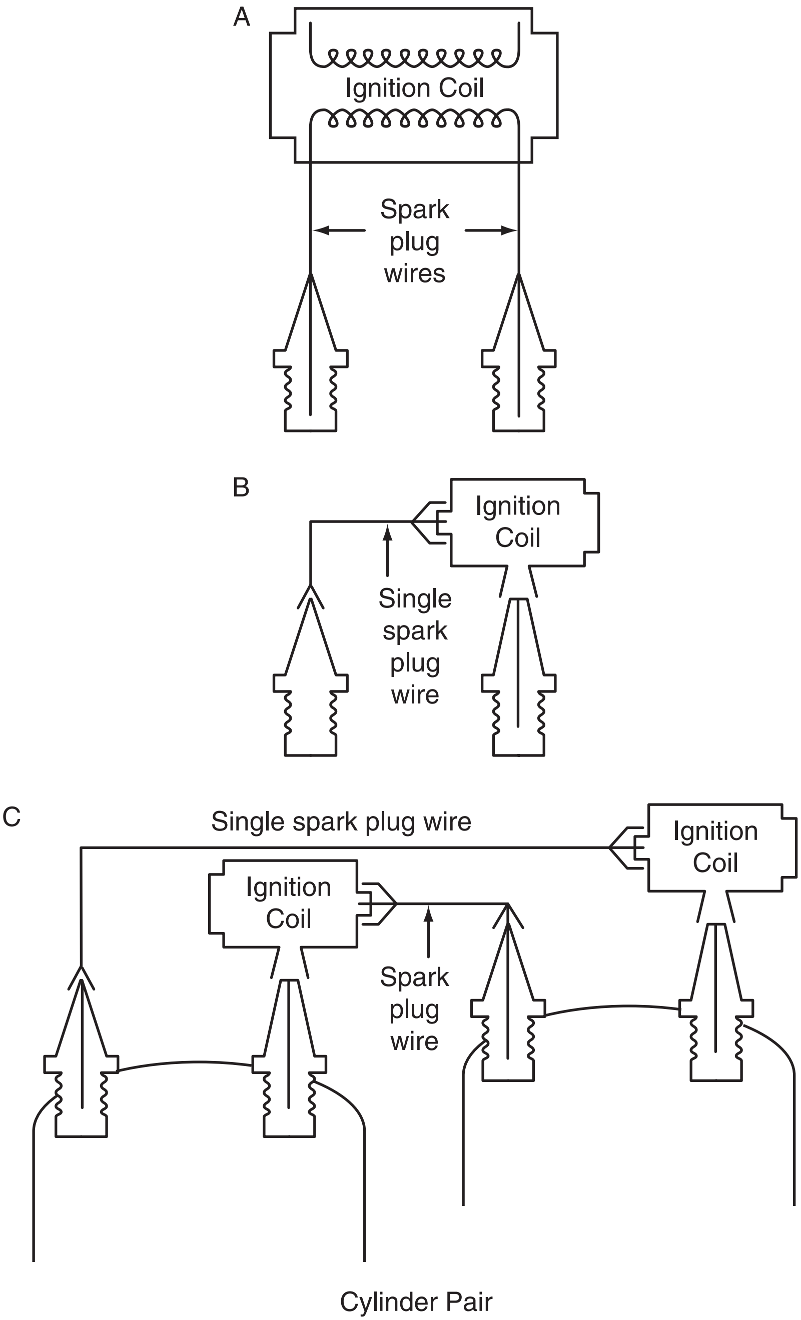


Figure 15–32 Waste spark configurations.

one-half of the secondary plug wires by designing a waste spark ignition coil to physically mount on top of one of the spark plugs, thus using only a single secondary plug wire to connect it to the companion cylinder's spark plug (Figure 15–32B). The Dodge Hemi V8 uses this concept as well, but with two spark plugs per cylinder. A waste spark ignition coil is mounted on top of one of the two spark plugs on one cylinder and uses a single secondary plug wire to connect to one of the two spark plugs on the companion cylinder (Figure 15–32C). Another waste spark ignition coil is mounted on top of the companion cylinder's remaining spark plug and is connected to the first cylinder's remaining spark plug by way of a single secondary plug wire. Therefore, each of the eight cylinders has an ignition coil mounted on top of one of its spark plugs, for a total of eight coils. Each cylinder's remaining spark plug receives spark through a secondary plug wire from the waste spark coil mounted at the companion cylinder.

This secondary ignition system can be a little confusing, with eight cylinders, 16 spark plugs, eight ignition coils mounted directly on top of the associated spark plugs, and eight secondary plug wires. However, if the technician applies the principles of ignition system design covered in this textbook, it should not be too difficult to study a system as unique as this one and figure out how it is designed to operate.

Detonation Control. From the beginning of the turbocharged four cylinder with multipoint fuel injection, the Chrysler multipoint system has had the ability to retard the timing on just the cylinder with knock. If knock occurs, the PCM has already recorded which cylinder was just fired. It then slightly retards the spark for just that cylinder. If knock continues, the PCM will begin to reduce turbocharger boost.

Wastegate Control Solenoid

Before 1985, turbocharged engines used three types of boost control. The first was the wastegate, as described in the "Outputs" section of Chapter 10. The wastegate actuator (Figure 15–33) opens the wastegate at a boost

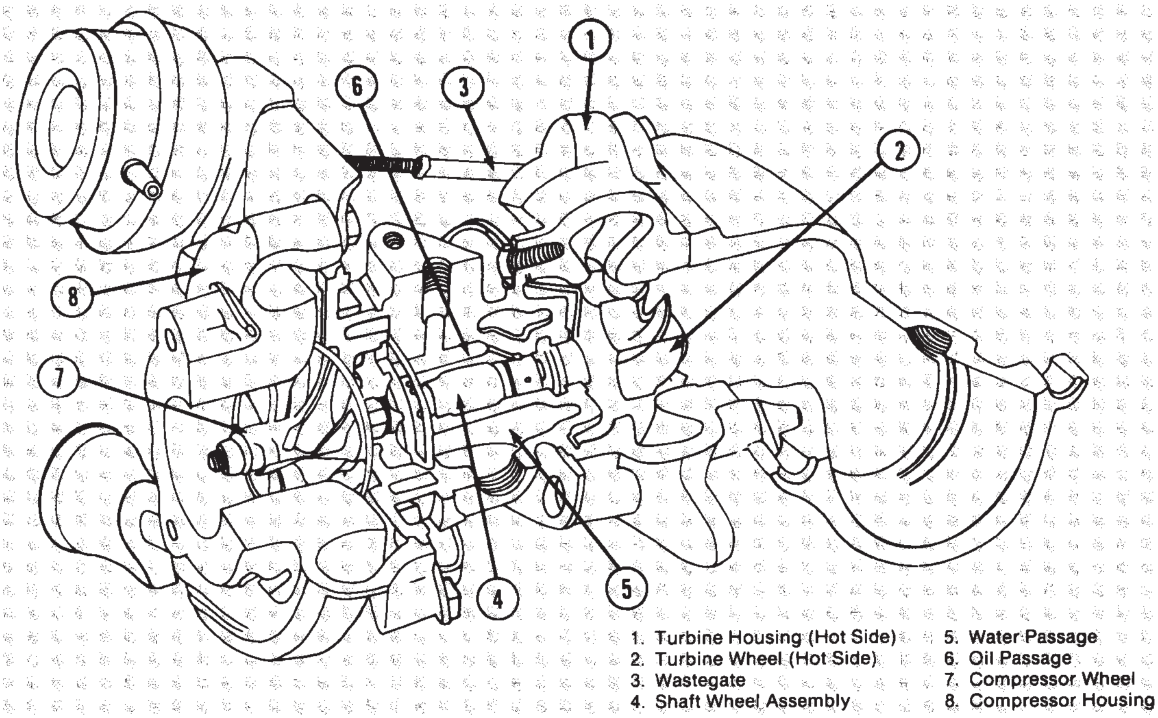


Figure 15–33 Turbocharger. (Courtesy of Chrysler Corp.)

pressure of 7.2 PSI. The second method has the boost pressure sensed by the MAP sensor. If boost exceeds 7.2 PSI (after snap acceleration, for example), the PCM recognizes the overboost and skips fuel injection pulses until boost pressure drops to 7.2 PSI. The third method uses the electronic engine speed governor: If RPM goes above 6650, the PCM stops fuel injection until the RPM drops to 6100.

In 1985, a fourth method was added. The PCM can operate a boost control solenoid that vents the line conveying manifold pressure to the wastegate actuator. If operating conditions are favorable, the PCM will pulse the boost control and bleed off some of the pressure. Under these circumstances, the boost pressure can actually go to 10 PSI before the actuator opens the wastegate. The PCM reviews these inputs for this calculation:

- barometric pressure
- engine speed (RPM)
- engine coolant temperature (ECT)
- intake air temperature (IAT)
- detonation (knock sensor)

The PCM also keeps track of the engine's "detonation history," how inclined it is to knock and under what circumstances, as well as how long it has been in boost.

Chrysler's Detonation Control

Chrysler puts strong emphasis on performance in their turbocharged vehicles, which is reflected in their detonation control strategy. You must prevent detonation, of course, or the engine will destroy itself. There are only two ways to stop detonation on a turbocharged engine under boost: reduce the boost or retard the timing. If you reduce the boost, you lose performance; if you retard the timing, you raise exhaust temperature, which was already critical under boost. Chrysler's solution of retarding timing to one cylinder raises exhaust temperature only slightly and allows the other cylinders to keep producing at their full capacity.

Revised Boost Control

Beginning in 1988, the turbo boost actuator control on the Turbo 1 engine works directly from the turbocharger itself rather than from the intake manifold pressure. This keeps the wastegate open during part-throttle operation and eliminates boost completely except at wide-open throttle (WOT). The advantages are these:

- Exhaust backpressure is lower.
- The intake air/fuel charge is cooler.
- The tendency to knock is reduced.
- Part-throttle fuel economy improves.

EGR Control Solenoid

This solenoid controls ported vacuum to open the EGR valve. When the PCM energizes it, vacuum to the EGR valve is blocked. The computer blocks vacuum when:

- The coolant temperature is below 70°F/21°C.
- The engine speed is below 1200 RPM.
- The engine is at WOT.

When the computer de-energizes the solenoid, allowing EGR actuation, a backpressure transducer also controls the EGR valve (Figure 15–34). Some vehicle systems have a

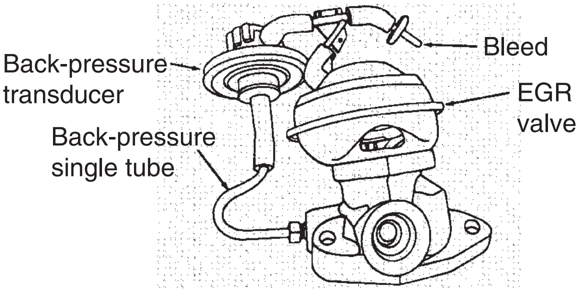


Figure 15–34 EGR valve and transducer. (Courtesy of Chrysler Corp.)

vacuum bleed in the line between the transducer and the EGR to prevent pressure buildup in the EGR valve.

EGR Valve Temperature Sensor

Chrysler installed a thermistor temperature sensor on California versions of the 1.5-L multipoint injection (MPI) engine in the 1988 Dodge Colt. The purpose of this sensor is to detect an EGR valve that does not open when actuated. When an EGR valve opens, hot exhaust gas flows through it, and the temperature of the EGR mounting flange should go up sharply. If the PCM sends an actuation signal to the EGR solenoid and does not quickly get a return signal from the EGR temperature sensor, it will store a fault code and turn on the MIL. Because of changes in cam profile that have reduced valve overlap, Chrysler was able to eliminate the EGR valve on the turbocharged 2.2-L engine in 1988.

OBD II EGR Monitoring Strategy

Chrysler OBD II PCMs monitor the ability of the EGR valve to both seal when closed and flow properly when opened using a strategy that is programmed into the PCM. When an EGR valve is opened, the exhaust gas flow that it allows into the intake manifold displaces ambient air that would otherwise be drawn into the cylinders, thereby reducing the amount of oxygen available for combustion. Fuel must also be reduced accordingly. With a carburetor (or feedback carburetor), the appropriate fuel reduction is automatic, but with any form of electronically pulsed fuel injection, it is up to the PCM to make the appropriate fuel reduction. Conversely, if the EGR valve is closed, because more ambient air is drawn into the cylinders, the PCM must also appropriately increase the fuel delivery to compensate.

Chrysler uses a strategy that allows the PCM to close an already open EGR valve while cruising in closed loop, but without increasing fuel delivery. It then watches for the pre-cat oxygen sensor and short-term fuel trim (STFT) to react accordingly. As the EGR valve is closed and the ambient air reaching the cylinders is increased, the fact that a change in fuel delivery was not made should cause the oxygen sensor to go lean. Simultaneously, the STFT values should go high, indicating the need to add fuel. If the PCM does not see the appropriate reactions made in response to the closing of the EGR valve, it then knows that either the EGR system was not allowing proper exhaust gas flow when it was open or the EGR valve is leaking and still allowing exhaust gas flow when closed. Thus, the PCM looks for the difference (or how much change occurs) in the oxygen sensor voltage/STFT values between the EGR being open versus closed. In this manner, the PCM can test the EGR valve/system for both flow and leakage.

Canister Purge Solenoid

The charcoal canister stores vapors from the fuel tank. As long as the coolant temperature is below 180°F/82°C, the PCM blocks the vent line to the throttle body by energizing a solenoid on the line. If the canister is not purged, it will gradually fill and will not be able to store any more vapors. If it purges too early or at other inappropriate times, it can drive the air/fuel mixture richer than the mixture control strategies can correct.

Except for the 3.0-L NS body style, all Chrysler engines now use a pulse-width modulated (PWM) purge solenoid valve to control the flow from the EVAP canister. The solenoid control circuit operates at a frequency of 200 MHz and is located in the PCM.

Radiator Fan Relay

The radiator fan relay supplies power for both the radiator fan and the A/C compressor clutch. The PCM grounds the relay coil whenever the coolant reaches a specified temperature or when the air conditioning is turned on. Both the fan and the compressor clutch are controlled by grounding their relay circuits.

Charging Circuit Control

Beginning in 1985, Chrysler vehicles have alternator output regulated by the PCM, replacing the voltage regulator. The PCM calculates the output based on the alternator's current output and on the battery temperature. The PCM controls the alternator output to between 12.9 and 15 V. When the key is turned on, an electronic voltage regulator (EVR) circuit inside the PCM uses pulse-width modulation to control the alternator field current. The PCM monitors the alternator output on a sensing wire from the ASD relay. If the charging rate cannot be monitored by the PCM, the field circuit duty cycle is limited to 25 percent so there is no high-voltage surge that might damage computer and sensor components (Figure 15–35).

A/C Cutout Relay

The A/C cutout relay is on the ground side of the A/C compressor clutch circuit, between the clutch and the A/C switch. When open, it stops the A/C clutch circuit. The PCM closes the compressor engagement circuit *except:*

- when the engine is operated at WOT
- when engine speed is below 500 RPM
- when the engine is cranked with the A/C switch on. The compressor cutout relay circuit remains open for 10 to 15 seconds after the engine starts.

Torque Converter Lockup Clutch

Beginning in 1988, the Torqueflite transmission came with a lockup torque converter on some vehicles. The PCM activates it under specific conditions, when:

- the coolant temperature is above 150°F, *and*
- the park/neutral (P/N) switch indicates the transmission is in gear, *and*
- the brake switch indicates the brakes are not applied, *and*
- the throttle angle, as reported by the TPS, is above a certain minimum.

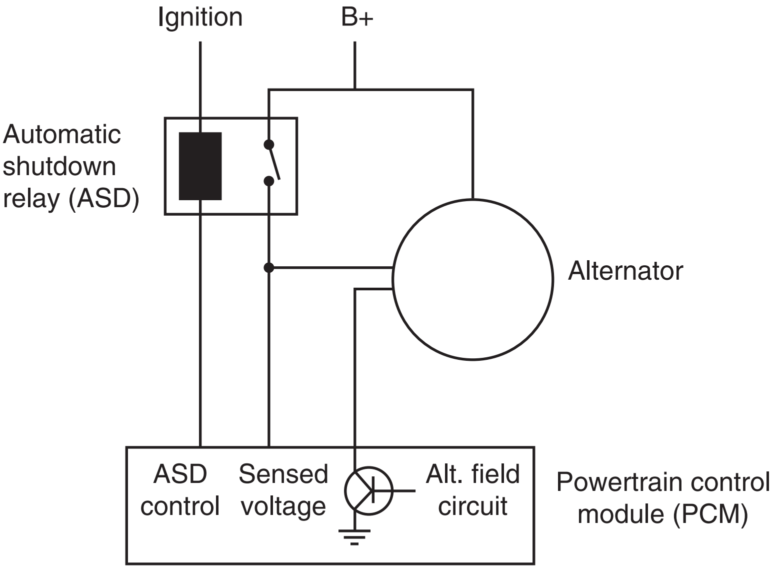


Figure 15–35 PCM alternator field control circuit.

The converter clutch works hydraulically, controlled by the computer. The actuation solenoid mounts on the valve body transfer plate and receives third clutch oil when the transmission goes into third gear. If the computer activates the solenoid by grounding its circuit while third clutch oil pressure is applied, the torque converter locks the crankshaft to the input shaft. Otherwise, the open solenoid bleeds off the oil pressure, and the torque converter clutch releases. This works in a way very similar to the GM and Ford systems.

Malfunction Indicator Light

The Chrysler malfunction indicator light (MIL), formerly known as the Power Loss Lamp (PLL) prior to OBD II standardization, serves the same purpose as the MIL on a GM or Ford vehicle. If the computer has encountered a fault in any of its sensors, actuators, circuits, or internally in itself, it stores a code and (for most faults) turns on the MIL and sets the system in limp-in mode. The lamp also comes on as a bulb check when the key first turns the ignition on. If the fault disappears within one driving trip, the lamp stays on until the next start-up. Then the lamp will turn off and the system will come out of limp-in, but the code will stay in the computer's memory for the next 30 key off/on cycles without the problem. In 1988 and later models, if a sensor fails, the computer generates its own substitute value for that sensor's readings and lights the lamp. If the sensor comes back into the proper range, however, the computer goes back into normal operation without the need for ignition cycling to exit limp-in mode. On Chrysler OBD II applications, the diagnostic trouble codes (DTCs) will remain on for most recorded faults until the PCM has seen 40 warm-up and cool-down cycles (as measured by the ECT sensor) without the fault reoccurring.

Vehicle Maximum Speed Governor

Also beginning in 1988, vehicles with 3.0-L and 2.2-L Turbo I engines have a vehicle maximum speed governor in the computer's program. Because of the speed rating of the tires installed on the vehicle, the computer shuts off all fuel if the vehicle exceeds 118 mph.

SMEC/SBEC Computer-Controlled Cruise Control

Most of the Chrysler SMEC/SBEC computer-controlled systems include the cruise control function in the engine management system. This system is similar to the Ford system described in Chapter 13 of this book. One additional feature of the Chrysler variation is a third solenoid called a *dump solenoid.* The ignition switch powers the dump solenoid through a fuse, the cruise control on/off switch, and the brake switch. Unlike most computer actuators, the dump solenoid has a fixed ground. Either turning the cruise control switch off or stepping on the brake will interrupt power to the dump solenoid, immediately bleeding off vacuum to the servo and letting the throttle return spring pull the linkage to idle.

CHRYSLER MULTIPLEXING SYSTEMS

Chrysler began networking onboard computers together over a data bus on its vehicles starting with the 1988 model year. Its first multiplexing system, known as Chrysler Collision Detection (C2D), was used from 1988 through 2000, using a twisted pair of wires for serial data communication among the various computers. Chrysler then introduced its second-generation multiplexing system on 1998 models. This system is known as the Programmable Communication Interface (PCI) system; it was installed on most Chrysler vehicles by 2001. The PCI system uses an OBD II standardized protocol known as a J1850 variable pulse-width single-wire system. Additional information is provided in Chapter 8 of this textbook. Some additional product knowledge on these systems is contained within the following paragraphs.

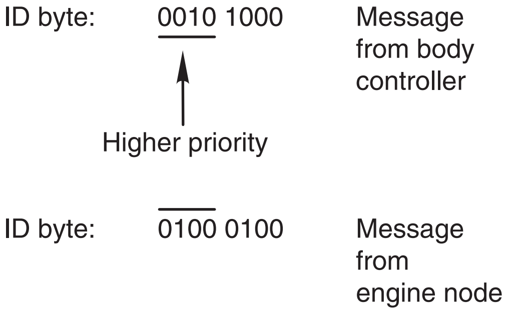


Figure 15–36 C2D and PCI protocol priority code.

Chrysler Collision Detection System

Each module (node) can broadcast information at any time the network is free. To resolve the problem of two modules attempting to send simultaneously, C2D systems prioritize each message. Each message starts with an ID code, a byte (an eight-digit binary number) that conveys the message's priority, content type, and size in bytes (Figure 15–36). The message ID byte with the most zeroes to the left of the first 1 has the highest priority and gets broadcast first. In 1992, Chrysler multiplexing systems transferred information at a rate of 7812.5 baud (7812.5 digital bits per second).

Different vehicles may have different components wired to their "internal Internet," but on Chrysler products these may include:

- Single Board Engine Controller (SBEC) or Next Generation Controller (NGC)
- Transmission Control Module (TCM)
- Body Control Module (BCM)
- Mechanical Instrument Cluster (MIC)
- Overhead Travel Information System (OTIS)
- Sentry Key Immobilizer Module (SKIM)
- additional modules as well, depending upon the year and model

Magnetic Interference

The data bus itself consists of two wires twisted together to reduce magnetic interference and the generation of false information by nearby electric components. Since the wires are twisted together, any magnetic induction affects both wires at the same time, canceling out most of the problem.

Programmable Communication Interface

The PCI system appears on the 1998 LH, the 1999 WJ, and the 2000 models. The star hub for this data bus is located in the junction block above the BCM. Communication tests among all controllers on the bus can be done at this central point. The voltage of this bus is approximately 7.5 V. Each module on the bus supplies its own bias and ground. The BCM is the primary node (also known as the *master* node) on many Chrysler vehicles; it uses a 1-kΩ resistor for termination.

ADVANCED CHRYSLER ELECTRONIC SYSTEMS

Like all other manufacturers, Chrysler's engineers have continued to advance the technology on its vehicles. These systems are, for the most part, designed similarly to those systems found on Ford and/or General Motors vehicles.

Electronic Throttle Control

The Electronic Throttle Control (ETC) system is an electronic system that physically decouples the throttle pedal from the throttle body. Used with the 5.7-L Hemi V8 engine in the 2005 Chrysler 300C and Magnum R/T, this system allows the PCM to directly control throttle plate movement electronically, thus eliminating the traditional throttle cable. The ETC system is often referred to generically as a "drive-by-wire" system. The ETC system provides several advantages, including lower emissions and quicker throttle response.

The components of the ETC system are a TPS to monitor throttle plate position, a DC motor that serves as the actuator used to control throttle plate position, and an accelerator pedal position (APP) sensor. In basic computer theory concerning an engine with a cable-operated throttle plate, the TPS is said to give the PCM information concerning *driver demand.* In an ETC system, driver demand information originates at the APP sensor.

The TPS is a two-channel potentiometer assembly, meaning that the TPS assembly contains two potentiometers and sends two signals to the PCM. The APP sensor is a three-channel potentiometer assembly, meaning that the APP sensor assembly contains three potentiometers and sends three signals to the PCM. In most applications, the potentiometers in the APP sensor operate electrically between different high and low values and/or in different directions. This allows the PCM to more precisely interpret exact throttle position than would be the case if they all delivered exactly the same voltage values at a given throttle position. The APP sensor is located in a throttle pedal assembly that is spring-loaded to give the driver a traditional pedal feel.

The PCM commands the DC motor to open or close the throttle plate(s) using bidirectional PWM commands. That is, it can issue pulse-width commands that instruct the motor to move the throttle plate(s) slowly or rapidly. “Bidirectional” refers simply to the fact that polarity applied to the motor can be reversed to move the throttle plate(s) in either direction (opening versus closing).

Compared to a cable-operated system, an ETC system provides quicker throttle response. In a cable-operated system on a fuel-injected engine, the amount of both fuel and air entering the engine must be increased to increase engine RPM and vehicle speed. The driver controls the volume of air allowed to enter the engine using the throttle cable, but the PCM controls the fuel. In a cable-operated system, the following must happen for the PCM to know to add additional fuel:

- The driver must move the throttle pedal.
- The throttle pedal must move the throttle cable.
- The throttle cable must rotate the throttle shaft, thus opening the throttle plate(s) to allow additional air to enter the intake manifold. Simultaneously, this action physically moves the TPS.
- The TPS must send the PCM a signal indicating that the throttle has opened the throttle plate(s).

In an ETC system, movement of the throttle pedal operates the APP sensor directly and immediately sends the signal to the PCM to increase engine speed. In an ETC system, the PCM controls both air and fuel, unlike the cable-operated system, in which the driver controls the air and the PCM controls only the fuel.

Use of an ETC system also has some other benefits:

- The PCM can use the ETC system to control engine torque directly when the traction control feature mandates it.
- The dedicated cruise control (speed control) servo is eliminated and speed control becomes a simple function of the PCM, no longer requiring additional hardware to control throttle position.
- The Automatic Idle Speed (AIS) actuator is eliminated. The PCM can now control idle RPM directly without the use of additional dedicated hardware.

Multi-Displacement System

Beginning in the 2005 model year, the Hemi 5.7-L V8 engine features a cylinder deactivation strategy when mounted in the 300C and Magnum R/T. This feature is referred to by Chrysler as the Multi-Displacement System (MDS) but is also known in the industry as Displacement-on-Demand (DOD), Active Fuel Management (AFM), or Variable Cylinder Management (VCM). The MDS is designed to increase fuel efficiency while giving the driver full access to the engine’s performance potential. The fuel savings is about three miles per gallon on the Chrysler/Dodge applications.

In actual operation, the MDS allows the PCM to run a V8 on four cylinders when the need for power is small. The engine always starts on all cylinders, but when cruising, when the need for power is reduced, the PCM does two things:

1. The PCM turns off the fuel injectors for four cylinders.
2. The PCM simultaneously closes all intake and exhaust valves on the disabled cylinders, which allows the disabled cylinders to act as an air spring does (using crankshaft power to compress the trapped air when the piston moves from BDC to TDC, but also returning power to the crankshaft when the piston moves from TDC to BDC). This avoids the energy losses that would occur if the disabled cylinder's piston were pulling down against manifold vacuum and pushing out against ambient air pressure on the exhaust side, known as "pumping losses."

A specially designed "switching lifter" is used on the MDS (Figure 15–37). It is designed with two portions—an inner body and an outer body—that can physically collapse in on each other. (This is similar to the manner in which a shock absorber operates.) A spring is designed as part of the lifter; it attempts to keep the lifter extended, although this spring has less tension than the valve springs that are used to close the cylinders' valves. For normal operation, the lifter has a locking pin that keeps the two halves from collapsing in on each other; the result is that the cam uses the lifter to open the valve. When the PCM wants to disable the valve, it energizes an oil solenoid, which provides oil pressure to push the locking pin so as to "unlock the lifter." At this point, the lifter collapses on the lifter's own spring tension. The spring is strong enough to keep the lifter following the cam lobe but not strong enough to overcome the valve-spring tension, thereby allowing the valve to stay closed. When the driver punches the throttle, the PCM instantaneously turns the fuel injector back on and de-energizes the oil control solenoid. The next stroke that allows the lifter to expand also allows the locking pin to lock the lifter in the extended position, and cylinder operation is restored.

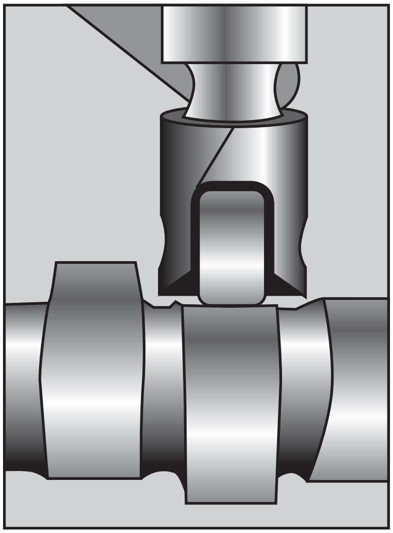


Figure 15–37 Lifter used in an MDS.

Some of the noteworthy technologies enabling the Chrysler MDS to operate efficiently include the speed of electronic control systems, the sophistication of the algorithms programmed into the control modules that control the systems, and the use of an ETC system. The Hemi V8 is able to transition from eight cylinders to four cylinders in 40 ms. If the MDS were to be used without ETC technology, when the PCM disabled one-half of the cylinders the driver would suddenly find that the power had been reduced and would have to push the throttle farther down to compensate and maintain a consistent cruise speed—naturally, a cause of concern for the driver. (Opening the throttle plate[s] farther allows the remaining cylinders to work more efficiently.) On an MDS that is used with an ETC system, a "smarter" PCM can make this compensation automatically as it disables cylinders or re-enables them. Thus, the driver is able to maintain a consistent throttle position as cylinders are disabled or re-enabled. In fact, when coupled with an ETC system, it is not likely that the driver will be aware of how many cylinders are actually being used, resulting in fewer driver concerns while enabling a higher degree of fuel economy.

Ultimately, the MDS allows the 5.7-L Hemi engine to combine the power and performance of a larger engine with the fuel efficiency of a smaller engine. By selectively deactivating half of the engine cylinders while cruising and operating all eight cylinders while idling and accelerating, the result is full power when you need it and increased fuel economy when power demands are reduced.

Electronic Stability Program

Chrysler is now using a feature on some of its vehicles that is designed to reduce the potential for a collision by aiding the driver's control of the vehicle if the vehicle's tires lose their grip with the road surface during cornering. Known as the Electronic Stability Program (ESP), this feature aids the driver in maintaining vehicle directional stability, providing both oversteer and understeer control to maintain the vehicle's behavior on the road surface. In a cornering situation where the tires have lost traction with the road surface, the vehicle's yaw rate is changed abnormally, resulting either in oversteer or understeer. (Yaw rate is a determination of how far left or right a vehicle has moved from its intended course.) If the vehicle's back end begins to fishtail (oversteer) during a turn, the Electronic Stability Controller (ESC) detects this through a "yaw rate and lateral acceleration sensor" and applies a braking pulse at the outside front wheel to help the driver stabilize the car (Figure 15–38). (This action allows the side of the vehicle on the inside of the turn to begin to move ahead of the other side, thus reducing the oversteer.) If the front end of the vehicle begins to drift to the outside of a turn (understeer), the ESC detects this and applies a braking pulse to the inside rear wheel. (This action places a drag on the side of the vehicle at the inside of the turn and allows the side of the vehicle on the outside of the turn to move ahead, thus reducing the understeer.) In both situations, it can also reduce engine torque as needed.

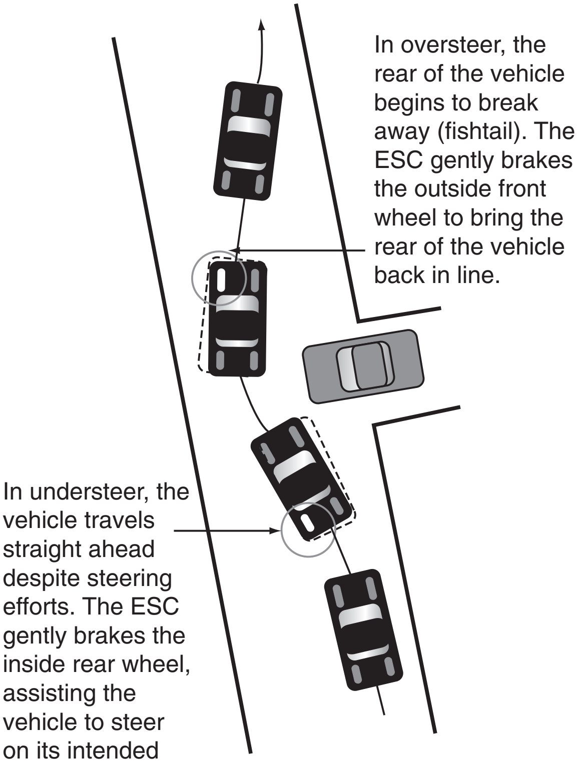

In oversteer, the rear of the vehicle begins to break away (fishtail). The ESC gently brakes the outside front wheel to bring the rear of the vehicle back in line.
In understeer, the vehicle travels straight ahead despite steering efforts. The ESC gently brakes the inside rear wheel, assisting the vehicle to steer on its intended

Figure 15–38 With an Electronic Stability Program, the Electronic Stability Controller reacts so as to correct understeer or oversteer.

✔ SYSTEM DIAGNOSIS AND SERVICE

A thorough diagnostic procedure is published by Chrysler Corporation for each model year and application. This driveability test procedure should be in the service manual you use on any particular car.

Onboard Diagnostics: Pre–OBD II

Besides directing the combustion activity of the engine, the PCM also monitors specific input and output circuits for faults (voltage values out of range or that do not change appropriately). If a fault is detected, the computer will store a two-digit code in its diagnostic memory. These codes and much other diagnostic information can be obtained by putting the system in one of its diagnostic modes using a Diagnostic Readout Box (tool C-4805 or other scan tool). On some systems the fault codes can be read out and the switches tested with the power loss lamp itself.

Test Modes

Diagnostic Test Mode. Connect the scan tool to the diagnostic test terminal under the hood. Turn the ignition on-off-on-off-on in 5 seconds or less. The readout box will then display any stored codes. When it is finished with everything stored in its memory, it displays code 55.

Switch Test Mode. Once the preceding test is complete and code 55 shows, make sure that all system input switches are turned off. Then turning on any of the input switches will cause the displayed code 55 to change for as long as the PCM gets the incoming signal. Turning the switch off causes the code 55 to reappear.

Actuator Test Mode. After the diagnostic test mode is completed and DTC 55 is displayed on the screen, select the Actuator Test Mode (ATM) feature from the scan tool's menu. (Many times, this feature is in the menu labeled "Functional Tests" or "Special Tests.") When the ATM feature is selected, you will be able to select from a list of PCM-controlled outputs, including emission solenoids, fuel injectors, ignition coils, speed control solenoids, the cooling fan relay, the ASD relay, and even the alternator field winding. As each item is selected, the PCM will cycle the requested circuit on and off once every 2 seconds for 5 minutes or until the test is deactivated. (Some circuits, such as the cooling fan, are simply momentarily pulsed once every 2 seconds; other circuits, such as the alternator field winding, are energized for 2 seconds and then de-energized for 2 seconds.) During this time, the technician can determine whether the output circuit is functioning properly. With the solenoids, this can be done by touch. Additionally, a vacuum pump and gauge can be used to test each solenoid functionally during this time. A spark tester should be used to test for spark from each ignition coil as it is selected. A DVOM or DSO should be used to verify that the PCM is switching the ground side of the alternator's field winding to ground for 2 seconds and then releasing the voltage to go to battery voltage for 2 seconds.

CAUTION: After using the ATM feature to pulse the fuel injectors, be sure to disconnect the ignition coil secondary wire from the distributor cap (DI system) or the ignition coil secondary wires from the spark plugs (EI system) and ground through a spark tester before the ignition coils are selected. Otherwise, the injected fuel may be ignited.

In reality, the Chrysler's ATM feature is equivalent to what is generically referred to as *active command mode.* The difference between this type of test and a self-test (as used by Ford Motor Company) is that in a self-test, the PCM energizes and de-energizes output circuits while monitoring the applied voltage (de-energized) and voltage drop (energized) associated with the circuit. The PCM then reports any failure to the technician as a DTC. With an active command mode (such as Chrysler's ATM), the PCM also energizes and de-energizes output circuits, but—because it lacks the circuit monitoring capability—it is up to the technician to determine the pass/fail status. Both Ford's self-test and Chrysler's ATM feature were carried forward into OBD II systems. Today both test types can be utilized as applicable on many more control modules than just the PCM, so it is critical that the technician understand both the capabilities and the differences of these two test types.

The ATM feature, as a form of an active command mode, is actually a feature designed to allow the technician to quickly narrow a problem down to the input side or the output side of the control module. For example, if you apply this concept to a modern Chrysler vehicle with an electronically controlled speedometer, if the customer's complaint was that the speedometer was not working, simply use a scan tool to activate the ATM feature from within the menu of the appropriate control module and then select the gauges. If the control module successfully moves the speedometer needle during the ATM test, you then know that the module can properly control the speedometer and the problem is not on the output side. You might then turn your attention to testing the input side of the system—for example, the VSS.

Another advantage of the ATM feature is the ability to use it as a component locator. For example, if two physically identical relays are mounted next to each other on a fender well, one being the ASD relay and the other one being the cooling fan relay, to determine which one is which, select one from the scan tool's ATM menu. Then, once the PCM begins to pulse it, simply identify the appropriate relay by touch. In certain cases, a solenoid, such as a canister purge solenoid, may be concealed from view by a wiring harness. If the canister purge solenoid is selected from the scan tool's ATM menu, you can identify the solenoid's location by sound.

Chrysler was the first domestic manufacturer to have such a sophisticated version of an active command mode prior to OBD II implementation. With OBD II implementation, most manufacturers now offer such a feature. However, many manufacturers require the use of the dealership scan tool to fully access all of the programmed active commands. In contrast, Chrysler's ATM feature allows a full array of commands to be carried out using most aftermarket scan tools.

Sensor Test Mode. Beginning in 1986, this test mode allows the technician to choose an individual sensor, and the scan tool will display the return voltage signal that the sensor is sending the PCM at that moment.

Engine Running Test Mode. This test checks a number of sensors and actuators in use. Connect the scan tool to the diagnostic test connector and start the engine. Observe the scan tool display. Once the oxygen sensor is hot enough, the display will switch between 0 (lean) and 1 (rich). The scan tool can also command the idle speed motor to increase idle speed. On turbocharged models, striking the intake manifold near the knock sensor with a tool, as explained in the service manual, will make the number 8 appear alongside the switching 0–1. The number 8, of course, indicates that ignition timing has been retarded.

Test Mode 10. The random-access memory (RAM) of the SMEC/SBEC computer is less volatile than that of the logic module. Removing battery power from it, one of the procedures used to clear the memory for logic module-equipped vehicles, may not erase the stored fault codes for some time. For these systems, there is another sensor test, mode 10. When the technician selects test mode 10, all fault codes are erased. Needless to say, fault codes should not be erased until after they have been written down for later diagnosis.

The SMEC/SBEC system also has a few additional fault codes and some changes from previous diagnostic procedures. For example, some of the harness connectors are hard to probe with test instruments; as a result, the revised diagnostic procedures may require disconnection of the harness and installing jumper wires.

Testing without the Scan Tool. Cycling the ignition switch on and off three times in 5 seconds triggers the logic module to flash codes through the MIL if the scan tool is not connected. It flashes on and off to indicate the code number. For example, two flashes separated by a short pause of about 0.5 seconds, followed by a pause of about 2 seconds and then three flashes, separated again with a short pause indicates code 23. Once the codes are flashed, the system goes into switch test mode. As long as it receives signals from the switches, the logic module will flash the MIL on and off in response to the input switches being correspondingly cycled. The other test modes, however, cannot be performed without the scan tool.

Driveability Test Procedure

The driveability test procedure is designed to use the test modes just described and to help diagnose engine performance complaints not caused by internal computer problems. It should be used whenever driveability problems are present. The first step, however, is to verify the problem. Ordinarily, the technician should drive the vehicle under the same conditions in which the owner discovered the problem.

The second step is a visual inspection. The driveability test in the Chrysler literature provides a guide for this, specific to the vehicle being diagnosed. If no problem is found during visual inspection, the most appropriate driveability test section should be used. If the engine does not start, obviously, use the no-start section. If the problem occurs only when the engine is cold, use the cold driveability section and so on. Once a driveability test section is begun, start at the beginning of the test and follow each step to the end.

WARNING: Because of the high fuel pressure in many of these systems, it is very important to relieve the pressure before opening the fuel system. Serious eye and fire hazards are present if a fitting is loosened while the system is still pressurized. In addition, use only the correct part numbers for fuel system hose and hose connections when making repairs.

OBD II Diagnostics

Chrysler OBD II systems require an OBD II scan tool for all diagnostic features, although, initially, Chrysler did retain manual methods of code pulling in parallel to OBD II scan tool methods on early OBD II systems. That is, on Chrysler's SBEC III systems, the diagnostic trouble codes (DTCs) may be pulled manually by cycling the ignition switch and counting pulses of the MIL (as in pre–OBD II systems), or a scan tool may be used. However, cycling of the ignition switch produces only two-digit codes as did their pre–OBD II systems. To obtain the OBD II five-digit codes, an OBD II scan tool must be used. On SBEC IIIA systems, the manual method was eliminated and all diagnostic functions must be done through an OBD II scan tool.

Once connected to the diagnostic link connector (DLC) under the driver's side of the instrument panel, Chrysler's *Diagnostic Readout Box* (DRB III) or *StarSCAN* scan tool, or an OBD II generic scan tool may be used to access several onboard computers, including the Powertrain Control Module (PCM), Transmission Control Module (TCM), Body Control Module (BCM), Mechanical Instrument Cluster (MIC), and the Antilock Brake Control Module (ABCM). Each of these modules provides the technician with the ability to access memory DTCs, perform functional tests such as the ATM, and perform certain other tests, depending on the system that is selected. For example, if the PCM is selected, the technician may adjust engine RPM in 100-RPM increments (typically from about 800 RPM to about 2000 RPM) through the scan tool's menu. And, in addition to DTCs, data stream information, and functional tests, PCM freeze frame data is also available. If the ABCM is selected, the technician may use the scan tool to bleed the ABS modulator assembly (part of the brake bleeding procedure). The TCM also allows the technician to select the vehicle's tire size from a menu to correct VSS calibration when tire size has been changed. To know what tests are offered with a particular scan tool, simply bring up the test menu for any of the modules that appear on the display screen.

SUMMARY

In this chapter, we covered single- and multipoint fuel injection systems used by Chrysler. We saw the role of the PCM in controlling combustion in the engine under all driving conditions. Likewise, we reviewed the way the computer controls the idle speed under various conditions, how it controls ignition timing, and how it prevents knock.

The text explained how the Chrysler system controls turbocharger boost to optimize power and engine life, first retarding spark to a specific cylinder, and only should that fail to end knock, by reducing turbocharger boost. The incorporation of control of the charging system output voltage was discussed. This accommodates battery condition when very cold and can also smooth the idle by reducing charge at low-torque engine speed. We also reviewed sensors such as the battery temperature sensor and the way the computer uses the voltage in the fuel pump circuit to calculate the alternator field strength.

We also looked at some of the newer systems that Chrysler is using on its vehicles, including the Electronic Throttle Control (ETC), Multi-Displacement System (MDS), and Electronic Stability Program (ESP). We also took a look at diagnostic procedures as they apply to both pre–OBD II systems and OBD II systems.

▲ DIAGNOSTIC EXERCISE

Describe the PCM system problems that would be caused by a high-resistance battery negative connection to the engine block and the kinds of tests you would use to determine if this was the problem.

Review Questions

1. The first full-function engine control system for Chrysler was the dual module system. Technician A says that the logic module sends a 5-V reference voltage to the sensors, makes calculations for the system based upon the input signals, and provides output instructions for the power module. Technician B says that the power module controls the output actuators according to commands from the logic module. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. Following the dual module system, the next engine control system that Chrysler used was which of the following?
   A. The JTEC system
   B. The SBEC system
   C. The NGC system
   D. The SMEC system
3. The engine control system used by Chrysler on Dodge trucks, the Dodge Viper, and Jeeps beginning in 1996 was which of the following?
   A. The JTEC system
   B. The SBEC IIIA system
   C. The NGC system
   D. The SMEC system
4. The engine control system that Chrysler introduced in 2002 is which of the following?
   A. The JTEC system
   B. The SBEC IIIA system
   C. The NGC system
   D. The SMEC system
5. Technician A says that, depending upon the year and model, the fuel pump on a Chrysler vehicle may be controlled by the ASD relay. Technician B says that, depending upon the year and model, the fuel pump on a Chrysler vehicle may be controlled by a dedicated fuel pump relay. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
6. The ASD relay may provide power for all *except* which of the following?
   A. The fuel injectors
   B. The Hall effect CKP and CMP sensors
   C. The ignition coil primary winding
   D. The O_2 sensor's heating element
7. Technician A says that the barometric pressure value in the PCM's memory is obtained from the MAP sensor. Technician B says that the baro read solenoid is used by the PCM to allow it to update the barometric pressure value in its memory at any time. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

8. What is the primary purpose for incorporating a range-switching (dual-range) temperature sensor on some Chrysler vehicles?
   A. Its circuit uses less current than a standard temperature sensor, thereby reducing the load on the alternator.
   B. It allows the PCM to use the same temperature sensor to measure both engine coolant temperature and intake air temperature.
   C. Its circuitry is simpler and therefore less confusing to a technician.
   D. It gives the PCM greater ability to fine tune the air/fuel ratio and spark timing due to its greater precision in measuring temperature.
9. What two sensors are sometimes combined into a single component on certain Chrysler vehicles?
   A. TPS and MAP
   B. IAT and MAP
   C. ECT and MAP
   D. TPS and ECT
10. In what model year did Chrysler begin using MAF sensors instead of MAP sensors as the primary engine load sensor on certain vehicles?
    A. 1985
    B. 1989
    C. 1994
    D. 2001
11. What type of tool should be used to measure and interpret the resulting signal from Chrysler's MAF sensor?
    A. A DC voltmeter
    B. An AC voltmeter
    C. A duty-cycle meter
    D. A Hertz meter
12. An optical sensor within a distributor contains all *except* which of the following components?
    A. A permanent magnet
    B. An LED
    C. A disc with slits in it
    D. A photocell
13. What type of sensor is used on Chrysler distributorless ignition applications to monitor crankshaft position (CKP) and camshaft position (CMP)?
    A. Permanent magnet
    B. Hall effect
    C. Optical
    D. Piezoelectric
14. What type of detonation (knock) sensor is used on Chrysler applications?
    A. Permanent magnet
    B. Hall effect
    C. Optical
    D. Piezoelectric
15. Why are returnless fuel injection systems being used on Chrysler vehicles?
    A. To reduce the potential for vapor lock
    B. To reduce evaporative emissions from the fuel tank
    C. To reduce the load on the fuel pump
    D. To improve cold engine performance
16. Technician A says that, beginning in 1988, Chrysler turbocharger boost is controlled to eliminate boost completely except at wide-open throttle. Technician B says that, beginning in 1988, Chrysler turbocharger boost is controlled to provide boost during cruise and light acceleration to increase fuel economy. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
17. To properly control alternator output, which of the following inputs is considered by the PCM?
    A. Monitored alternator output only
    B. Battery temperature only
    C. Throttle position
    D. Both A and B
18. Regarding the addition of an ETC system to an engine, which of the following statements is *false?*
    A. The AIS actuator is eliminated.
    B. The speed control servo is eliminated.
    C. The throttle cable is eliminated.
    D. An ETC system is less responsive than a mechanical throttle cable.

19. How does a Chrysler MDS respond when the need for power is reduced?
    A. The PCM disables only the spark for one-half of the cylinders.
    B. The PCM disables the fuel injectors for one-half of the cylinders and allows the associated valves to continue to operate to allow the engine to pump air through these cylinders.
    C. The PCM turns off the fuel injectors for one-half of the cylinders and opens the associated valves
    D. The PCM turns off the fuel injectors for one-half of the cylinders and closes the associated valves.

20. If the front end of a vehicle with the ESP feature begins to drift to the outside of a turn (understeer), to which wheel will the ESP system apply a braking pulse to correct the understeer?
    A. Inside rear wheel
    B. Inside front wheel
    C. Outside rear wheel
    D. Outside front wheel

Chapter 16

European (Bosch) Engine Control Systems

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ☐ Describe the two basic types of Bosch fuel injection systems.
- ☐ Explain the distinction between the Motronic system and the earlier Bosch fuel injection systems.
- ☐ Identify the various operating modes of the Motronic system and the operating conditions to which they relate.
- ☐ Define the inputs used with a Motronic fuel injection system.
- ☐ Define the outputs controlled by a Motronic fuel injection system.
- ☐ Understand the basic diagnostic steps of a Motronic fuel injection system.

KEY TERMS

Continuous Injection System
Lambda
Motronic
Pulsed Injection System

The Robert Bosch Corporation does not build cars or engines but rather components and control systems. Vehicle manufacturers buy these specially engineered components and control systems from the Bosch Corporation to use on their own vehicles. An early pioneer in fuel injection systems, the Bosch Corporation makes many of the products found on most German and Scandinavian cars, as well as those on many American and Japanese vehicles. Bosch also licenses several of its systems for manufacture by other firms, so an understanding of the Bosch systems in turn provides an understanding of many systems built by other sources as well. A modern English car with a Lucas control system, for example, is actually controlled by Bosch-designed components and controllers.

Some of the more advanced technological systems engineered by Bosch include Electronic Throttle Control and the Electronic Stability Program, already described in the General Motors, Ford, and Chrysler chapters of this textbook. These systems have been implemented on European vehicles as well. In fact, these systems tend to be implemented on the German vehicles ahead of their implementation on U.S. vehicles.

The purpose of this chapter is to discuss the Bosch engine performance control systems and components used over time. While this chapter generally refers to those systems found on European vehicles, many of the components discussed in this chapter also are found on both U.S. and Asian vehicles.

SYSTEM OVERVIEW

The Bosch company has been involved in fuel injection since the 1920s, when it began with diesel injectors. Its experience with gasoline injection goes back to military vehicles in the late 1930s. One of its earliest systems for passenger cars was the direct, diesel-style injection system used on a few of the gasoline-fueled Mercedes-Benz SLs. That system was a mechanical forced injection system very similar to diesel injection systems used on trucks.

All the Bosch engine management systems are computerized developments of earlier fuel injection systems, mostly mechanical. While our focus in this book is on computer-controlled systems, it would be difficult to understand what the Bosch engineers were doing without some explanation of the earlier mechanical systems on which the computerized systems are based.

While Bosch has built a version of throttle body injection for a limited number of European manufacturers, all of the systems used on vehicles imported into the United States have been multipoint-injection systems. The advantages of multipoint fuel injection are the same for Bosch as for any other injection system builder.

Bosch systems work in one of two basic ways: **pulsed injection systems** and continuous systems. D-Jetronic and L-Jetronic systems are pulsed (Figure 16–1); the K-Jetronic system is continuous (also referred to as the **Continuous Injection System** [CIS]) (Figure 16–2). The

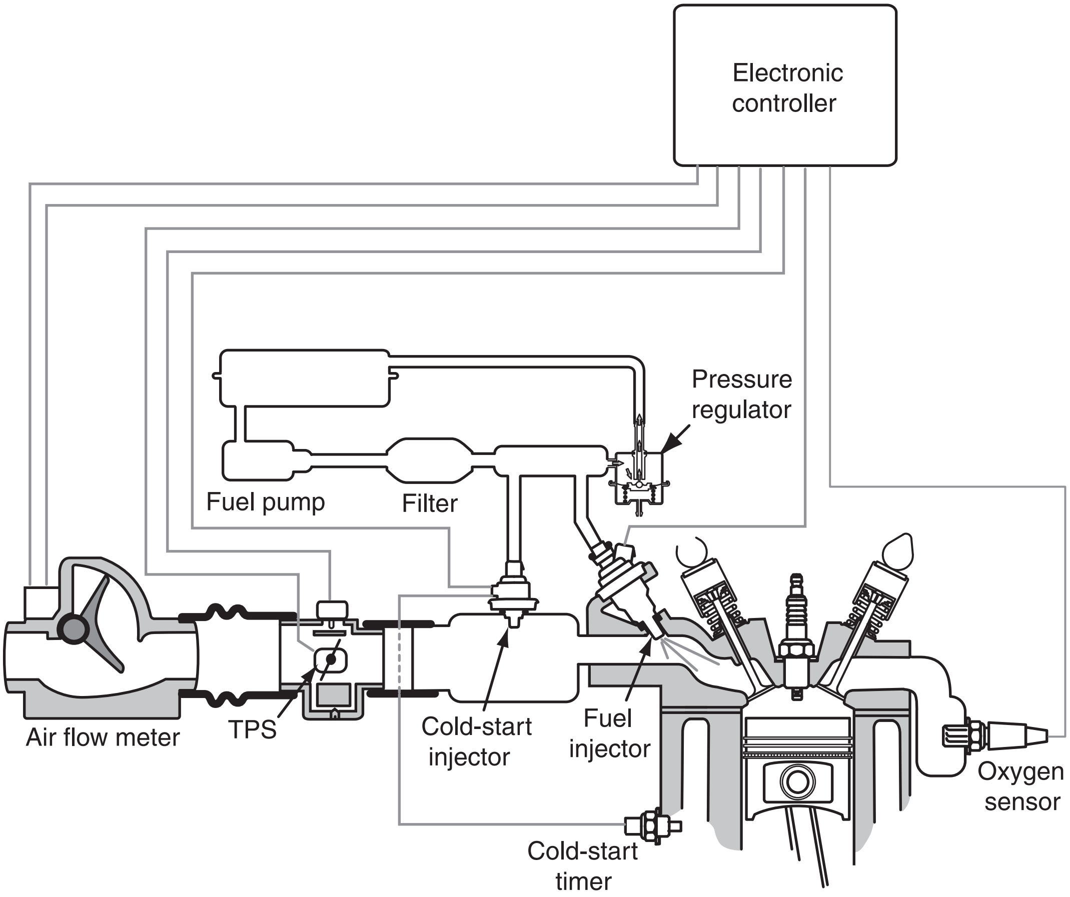


Figure 16–1 Pulsed injection system.

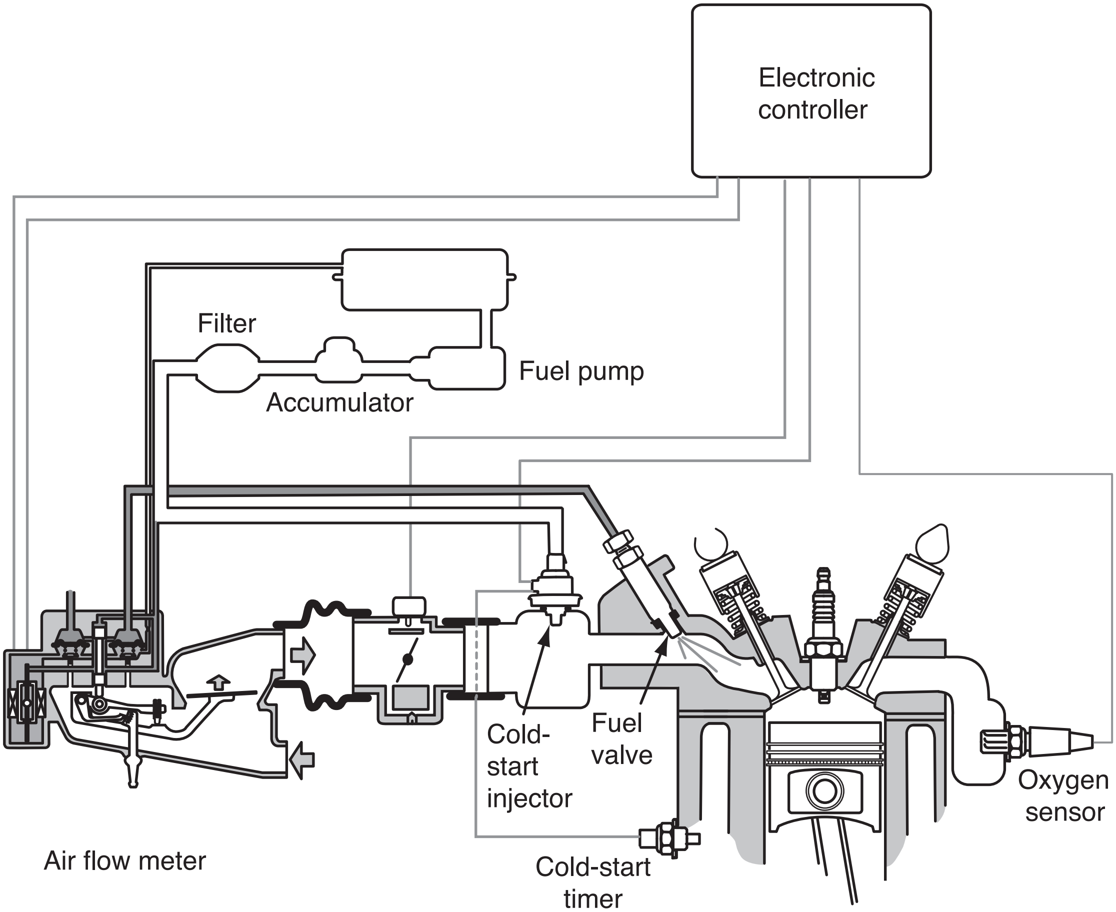


Figure 16–2 Continuous injection system.

D comes from the German word for (intake manifold) pressure, *Druck,* the major sensor in that system. The L comes from the German word for air, *Luft,* the air flow sensor or meter being that system's major sensor. The K comes from the German word for continuous, *Kontinuerlich,* because the fuel flows continuously from that system's injectors as long as the engine is running. When the letter E is added, it indicates the system is electronic, that is, controlled by a computer. The term **Motronic** applies to the more fully developed engine management systems, covering spark timing, fuel injection, and some other vehicle functions. In general, a Motronic system uses a single computer to manage all engine functions, while the earlier systems used independent controllers, typically one for ignition and another for fuel injection.

The pulsed injection systems work either sequentially or in clustered groups, varying fuel delivery by pulse width, just as domestic systems do. The continuous systems spray fuel from port injectors whenever the engine is running, varying the amount sprayed to correspond with the amount of air entering the engine. Both types of systems have evolved into computer-controlled systems, with improved driveability, fuel economy, and emissions quality. Once warmed up to operating temperature and driving normally, the system controls the air/fuel mixture by a closed-loop feedback process (Figure 16–3).

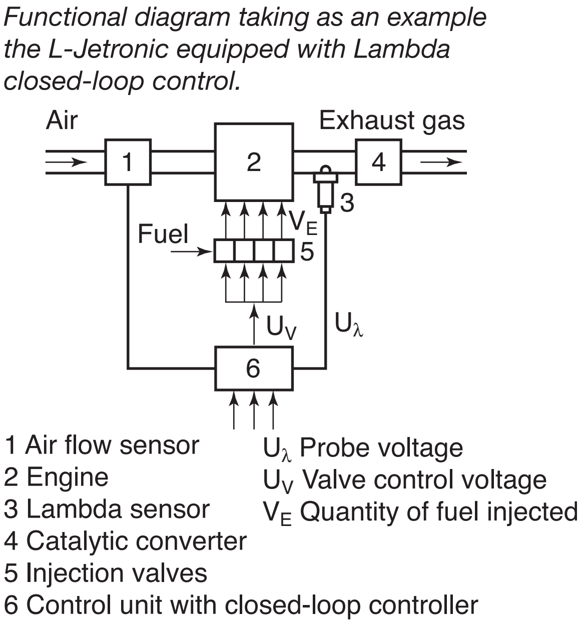

Functional diagram taking as an example the L-Jetronic equipped with Lambda closed-loop control.
Air
Exhaust gas
1
2
4
3
Fuel
V_E
5
U_V
U_λ
6
1 Air flow sensor
2 Engine
3 Lambda sensor
4 Catalytic converter
5 Injection valves
6 Control unit with closed-loop controller
U_λ Probe voltage
U_V Valve control voltage
V_E Quantity of fuel injected

Figure 16–3 Closed-loop schematic. (Reprinted with permission from Robert Bosch Corporation.)

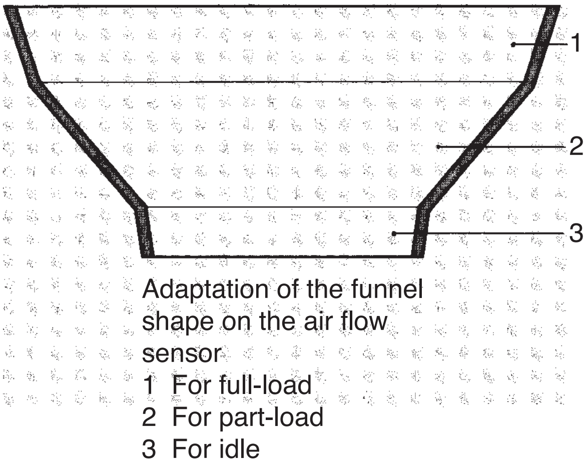


Figure 16–5 K-Jetronic air cone taper for different air flows. (Reprinted with permission from Robert Bosch Corporation.)

The continuous injection (K-Jetonic and KE-Jetronic) systems are the most common of the Bosch systems, used on virtually all European makes at different times. Incoming air lifts or lowers (depending on the vehicle manufacturer) a plate suspended on a lever in a specially shaped cone (Figures 16–4 and 16–5). The movement of the plate (in original mechanical systems) completely determines the amount of fuel injected through the fuel distributor. In the later computerized systems, the control unit can vary the mixture by varying the pressure differential between the upper and lower parts of the fuel distributor in response to the signals from sensors, thus controlling the delivered air/fuel mixture (Figure 16–6). The control unit also employs programming for enrichment under cold engine, acceleration, and some other driving conditions.

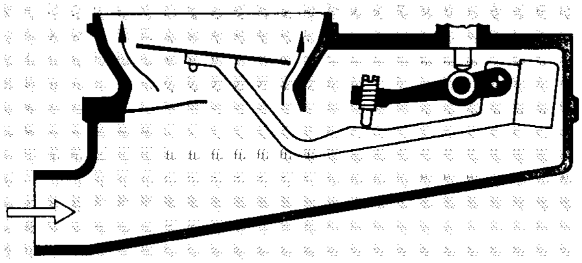


Figure 16–4 K-Jetronic air cone. (Reprinted with permission from Robert Bosch Corporation.)

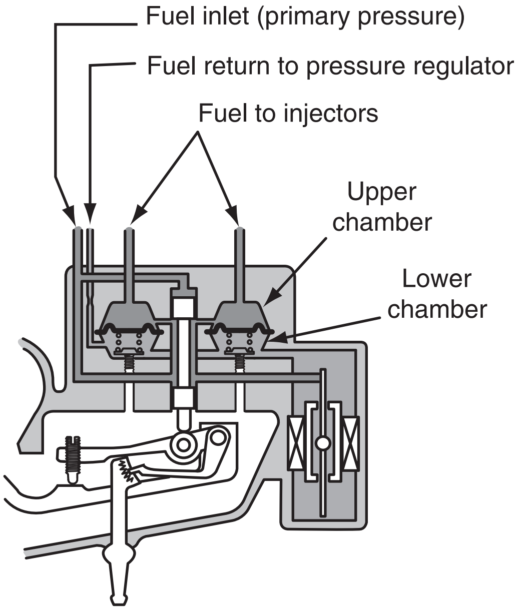

Fuel inlet (primary pressure)
Fuel return to pressure regulator
Fuel to injectors
Upper chamber
Lower chamber

Figure 16–6 Air sensor plate and fuel plunger.

CONTINUOUS INJECTION SYSTEM

Mixture Control Unit

The major fuel and air component of the Continuous Injection System is the mixture control unit (Figure 16–7). This combines the air flow sensor plate and the fuel distributor. As the incoming air lifts (or on some models lowers) the plate, it moves a lever directly connected to the fuel distributor. The lever lifts a precisely machined plunger in a barrel with special slots to meter the fuel to each cylinder (Figure 16–8). The farther the plunger is raised, the more fuel passes the plunger, then goes through the barrel and into the cylinders, corresponding to the increased amount of air moving past the air plate.

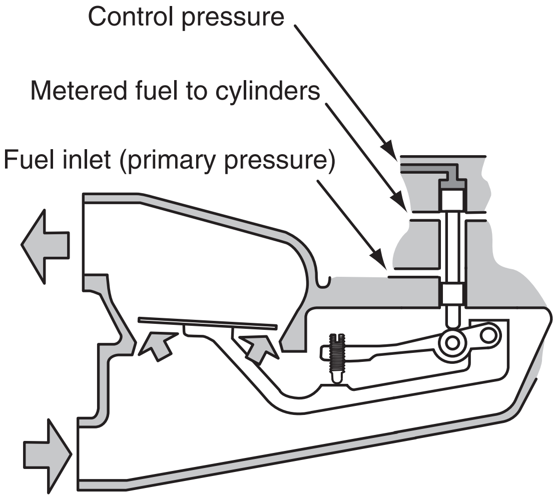


Figure 16–7 Mixture control unit.

The original K-Jetronic systems worked mechanically to adjust the air/fuel mixture. Once the system became computer controlled to adjust the mixture in response to signals from sensors, the fuel distributor was modified to include a pressure actuator, a device to vary the pressure difference between the upper (delivery) and lower (control and return) halves of the fuel distributor (Figure 16–9).

The control unit does this by varying the current (amperage) flowing through the pressure actuator, which then controls fuel bypass, pressure difference, and delivery rate. The current passes through an electromagnetic coil that raises a restrictor baffle in the fuel return line, determining the control pressure. Electromagnetism is directly proportional to the current, regardless of the voltage. The pressure difference between the two halves of the fuel distributor flexes a thin metal

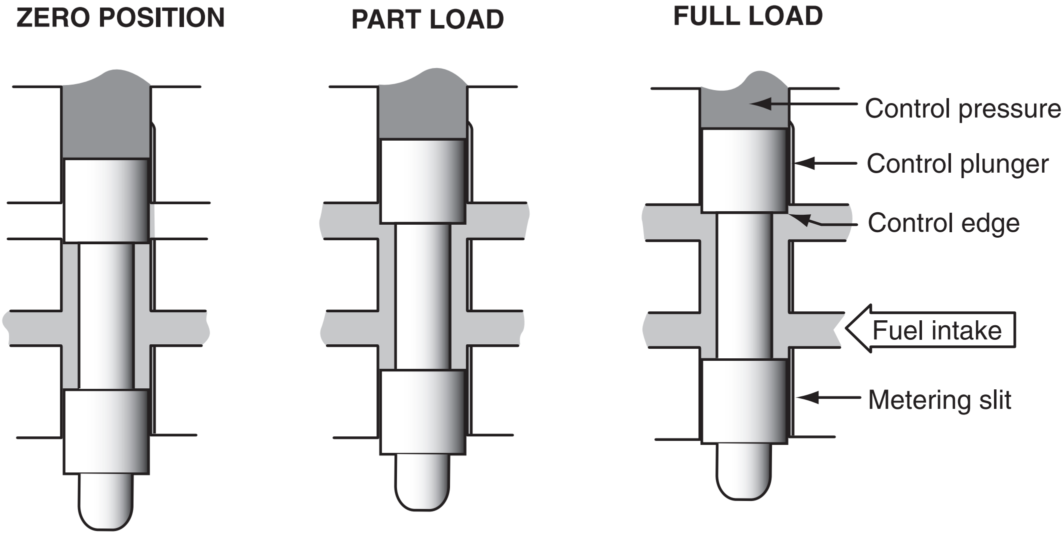


Figure 16–8 Fuel plunger.

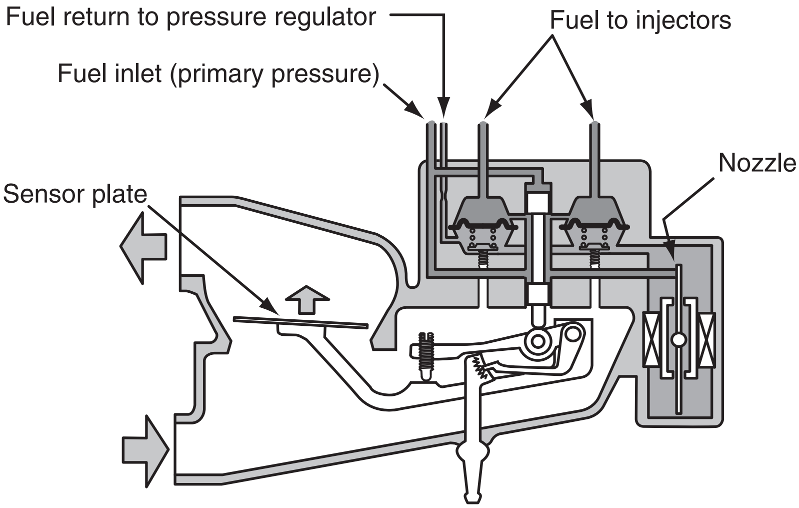

Fuel return to pressure regulator
Fuel to injectors
Fuel inlet (primary pressure)
Nozzle
Sensor plate

Figure 16–9 Pressure actuator.

diaphragm that allows fuel to pass into the injector lines. The more the diaphragm flexes down, the more fuel is injected and vice versa (Figure 16–10). By returning more fuel to the tank, the actuator reduces the pressure difference, flexes the diaphragm up, and reduces fuel delivery. By restricting return fuel flow to the tank, the actuator increases the pressure difference, flexes the diaphragm down, and increases fuel delivery.

Bosch continuous injection systems are often called mechanical fuel injection systems, but it should be noted that they are primarily hydraulic in the way they work.

Most continuous injection systems are installed separately from the engine, on a bracket in the intake air line. On certain V-form engines, notably Mercedes-Benz and Volvo, the control unit is mounted directly on the engine, much like a carburetor.

The injectors in a continuous system spray whenever the fuel pump is operating (powered as on domestic systems through a relay). On many systems, the injectors include a special vibrating needle in the tip, which aids in atomizing the fuel. Often the action of these vibrating needles is audible as a hiss with the hood open and the engine at idle. This is normal and does not require any corrective action.

PULSED SYSTEMS

The pulsed injection systems (D-Jetronic, L-Jetronic, and LH-Jetronic) vary the air/fuel mixture by varying pulse width, just as on domestic systems. As we will see, the sensors and actuators work very similarly.

The earliest of the modern Bosch systems was the D-Jetronic. Named for the German word for pressure, the D-Jetronic uses intake manifold

Diagnostic & Service Tip

Because Bosch D-Jetronic systems calculate fuel delivery entirely by intake manifold pressure, a vacuum leak in these systems will not cause a bad idle from a lean mixture (unless there is a large vacuum leak to just one cylinder). However, a vacuum leak does cause a high idle speed in a way that can be puzzling to technicians unfamiliar with the system. Checking for vacuum leaks is done in the same manner as with other fuel injection systems.

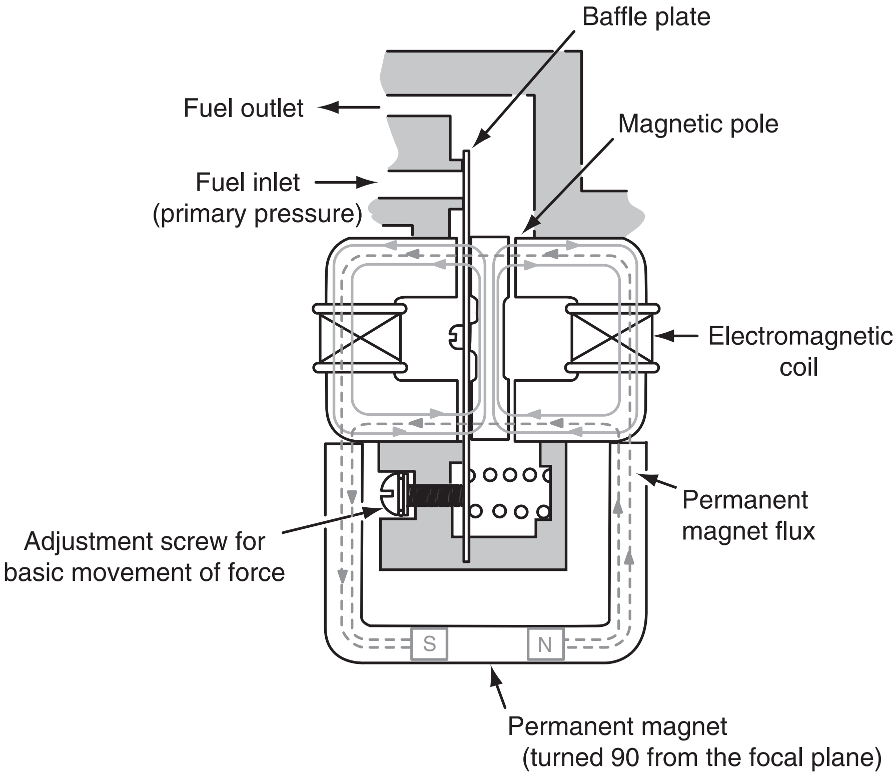


Figure 16–10 Operation of fuel distributor diaphragm.

pressure as the principal input for the calculation of how much fuel to inject. Although Bosch discontinued this system years ago after tests and experience showed that air mass measurements were much more accurate for such calculations, the intake manifold pressure information is still used on many systems, as we have seen in previous chapters.

The D-Jetronic systems are also unique in their use of analog computers. A few of the early L-Jetronic systems also used an analog computer. These systems work more slowly and by variable voltages rather than by faster, digital systems. D-Jetronic systems only control fuel injection; they have no control over ignition. Most of them do receive a signal from the distributor (from a second set of contact points in early models) to time the fuel spray.

The pulsed-injection Bosch systems do not employ the air flow plate or fuel distributor from the K-Jetronic systems. Instead, they measure the incoming air volume (or in later systems, mass), and the computer calculates the proper pulse width under all engine conditions, opening the injectors to deliver the correct amount of fuel. The injectors for these systems are identical to those in domestic fuel injection/engine management systems. The most important sensor for this operation (after the engine is started and warmed up) is the air flow meter. While this is similar to the air flow meter used on some Ford systems, it is a Bosch-engineered component, so we describe it in some detail here.

Air Flow Meter

The air flow meter is basically a lightly sprung swinging door in the air stream, sharing a pivot shaft with a potentiometer that modifies the return voltage signal to the computer (Figure 16–11).

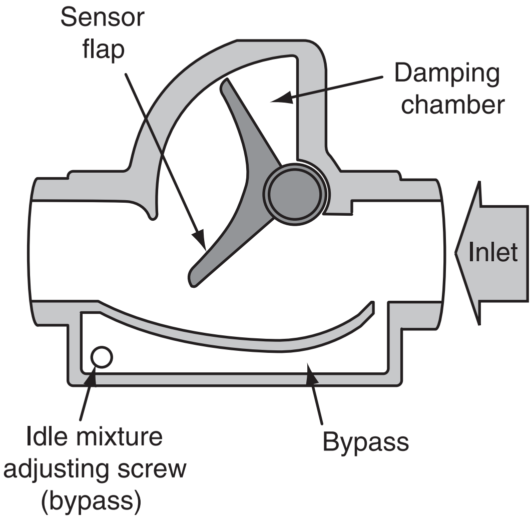


Figure 16–11 Air flow meter.

Paired with the air flow meter door is a second door of equal size in a blind passage. The second door serves two functions: On four-cylinder engines, the individual cylinder pulses can be so distinct that they create pulses in the intake manifold, moving the sensor back and forth with each pulse. This is particularly likely at low engine speeds. The second door serves as a damper to prevent this sensor door pulsing. If the door were allowed to pulse, the computer would receive inaccurate signals about the amount of air taken into the engine. On many of the swinging-door air flow meters, there is an additional door or pop-out plug in the center of the flap to allow a backfire to occur without destroying the expensive air flow meter when the air door would otherwise slam shut.

A later version of the L-Jetronic system, called the LH-Jetronic, uses a hot-wire air mass sensor that works just like the hot-wire air mass sensors used in domestic engine management systems (Figure 16–12).

MOTRONIC

The Motronic system is Bosch's first multifunction engine management system. In addition to the air/fuel mixture, it controls ignition timing and dwell. The system may also be designed to control idle speed, EGR operation, evaporative emissions, automatic transmission, and a turbocharger, depending on vehicle application.

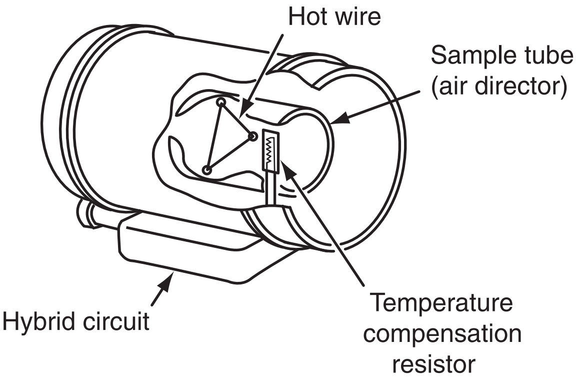


Figure 16–12 Air mass sensor.

ELECTRONIC CONTROL UNIT

The Bosch Motronic system is similar to the L-Jetronic system and, like its predecessor, controls fuel metering with pulse-width modification. The Motronic system's computer, or electronic control unit (ECU), is a digital computer with the ability to control additional functions, such as spark timing. (It should be noted that the term *ECU* still continues to be used generically to refer to an *electronic control unit* that may be used to control any type of system or an undefined system, while *PCM [powertrain control module]* is

Bosch and Imports

Most of the imported European cars with a comprehensive computerized engine control system use a Bosch system. It first appeared on selected BMWs. Most of the systems used on Japanese cars imported into the United States are built using Bosch patents. Practically all the gasoline engine multipoint-injection systems for domestic vehicles use Bosch components or patents.

Inputs

Air flow meter
Engine speed
Crankshaft position
Coolant temperature
Air temperature
Lambda sensor (oxygen sensor)
Knock sensor
Altitude sensor
Starter signal
Battery voltage

Control unit

Main relay

Outputs

Fuel injection
Fuel pump relay
Ignition timing
Dwell control
Rpm limit
Peak coil current cutoff

The following functions are system options (available to the vehicle manufacturer):

Rotary idle adjuster
Turbo boost control
EGR control
Canister purge
Transmission control
Start-stop control

Noncomputer-controlled functions: fuel pressure regulation, fuel pressure pulsation damper, cold-start injector and thermo-time switch, and auxiliary air device (used in place of rotary idle adjuster)

Figure 16–13 Overview of Motronic system.

an OBD II standardized term that refers to an ECU that controls specific systems that affect the vehicle's powertrain [engine and/or transmission performance]. Because our discussion here concerns the original Bosch fuel injection systems without defining a make of vehicle that they might be installed in, we will use the original Bosch term *ECU*). *An* overview of the Motronic system is provided in Figure 16–13.

The ECU's mounting brackets also serve to dissipate heat from the power transistors that drive the ignition and injectors (Figure 16–14). A 35-pin connector connects to the vehicle's system harness.

Main Relay

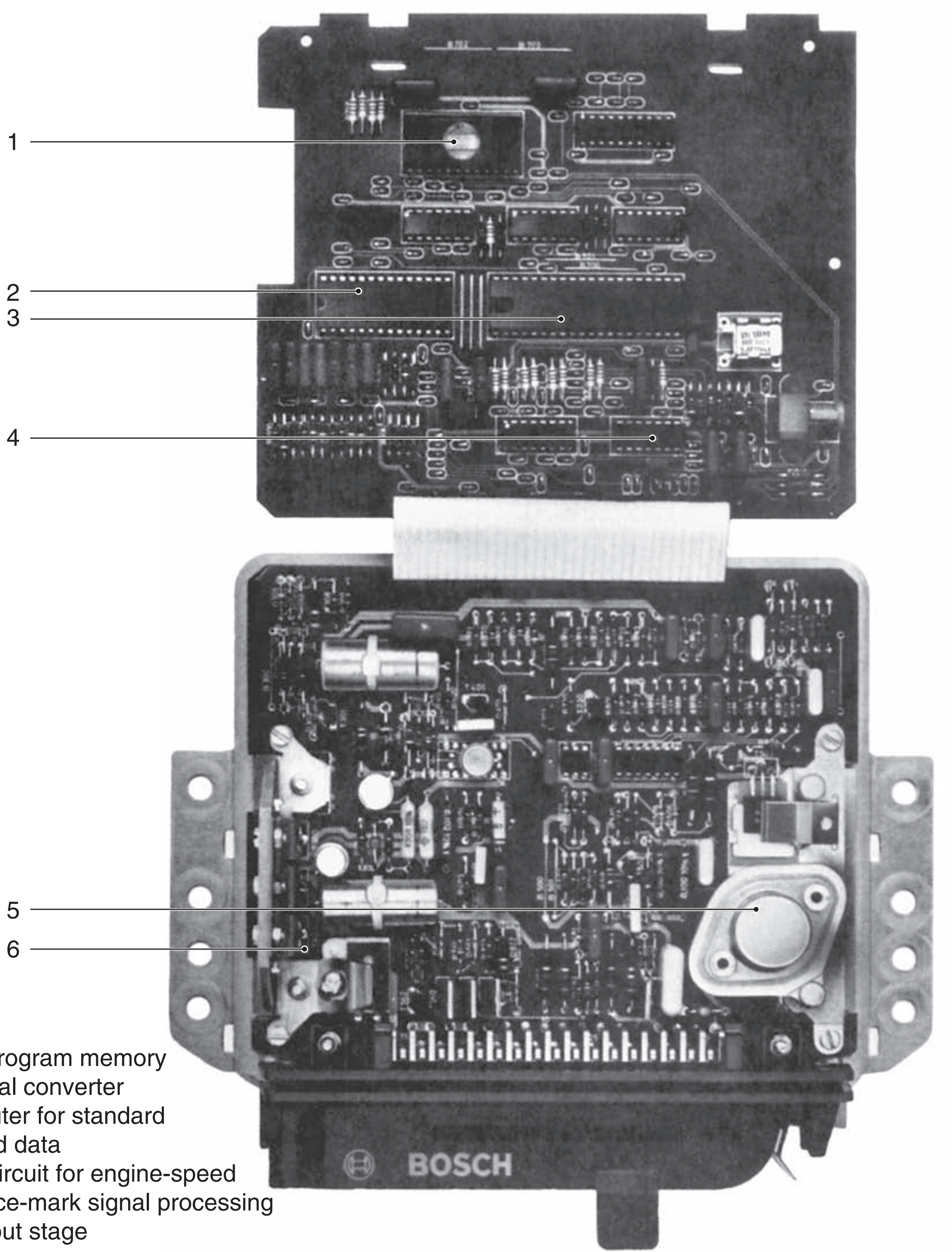
A main relay, similar in operation to the power relay used on Ford EEC systems (see Chapter 13), powers the ECU as soon as the ignition is turned on. This relay also includes a diode to protect the ECU against voltage surges and accidental polarity reversals.

Onboard Diagnostics

The first few model-year applications of Motronic do not feature any form of self-diagnosis, except that if a fault is detected in the closed-loop operating circuit, a calculated pulse width aimed at maintaining an air/fuel mixture near stoichiometric is used. Later versions, particularly those imported after the implementation of OBD II regulations, include extensive self-diagnostics.

OPERATING MODES

The ECU is programmed to use different operational strategies as driving conditions change. Most of the differences in strategy occur during open-loop mode.



1 Additional program memory
2 Analog-digital converter
3 Microcomputer for standard program and data
4 Integrated circuit for engine-speed and reference-mark signal processing
5 Ignition output stage
6 Fuel-injection output stage

Figure 16–14 ECU. (Reprinted with permission from Robert Bosch Corporation.)

Cranking

Two fuel-metering programs can be employed during engine cranking. One is based on cranking speed, the other on temperature. At lower crank speeds, the fuel quantity injected stays constant regardless of air flow fluctuations (input from the air flow sensor is not reliable in these conditions because of pulsing caused by individual cylinder intake strokes). At higher cranking speeds, air intake diminishes slightly as a result of lower volumetric efficiency, so fuel quantity injected is also reduced. During cold cranking, the ECU adds an enrichment program in addition to the speed-dependent program. Some versions of the Bosch systems include a cold-start injector in the intake manifold (Figure 16–15), while some merely add injection pulses at the port injectors. Ignition timing is also adjusted, depending on cranking speed and coolant temperature. The cold-start injector system is very similar to those used on several American vehicles: It sprays a priming load of fuel into the cold intake manifold upstream of the main injectors. The extra distance the fuel must travel to reach the cylinders affords slightly more time for the gasoline to vaporize, making start-up easier.

On applications without a cold-start injector, the ECU pulses the injectors several times per crankshaft revolution during cranking instead of the normal once per engine cycle. This should both enhance fuel evaporation and avoid flooding the spark plugs with wet fuel. The enrichment decays to zero over a specific, small number of engine revolutions. The number depends on the engine coolant temperature when cranking begins. If the RPM reaches a preset value before the specified number of revolutions has occurred, the cold-cranking enrichment program stops anyway. The preset RPM value also depends on the engine coolant temperature when cranking begins.

Diagnostic & Service Tip

Sometimes when a vehicle has been used in a warm climate for a season, a certain amount of moisture can collect in the fuel line to the cold-start injector. This moisture can allow rust to form since the injector does not have occasion to turn on and flush out the contamination. When cold weather returns in the fall, the injector turns on but is plugged with rust, and the car will not start. At this point, you must service the cold-start injector by cleaning or replacing it.

After Start-Up

As an engine starts cold, the intake port surfaces and combustion chamber walls, ceiling, and piston top are also cold. Fuel can condense on these surfaces, leading to poor combustion. During the brief time it takes for these areas to warm up, the ECU initiates a post-start enrichment program to maintain a good idle quality and improve throttle response. Once this begins, the enrichment also decays within a brief time to zero. This period of time depends on coolant temperature at the time of start-up cranking. The ECU also advances the ignition timing relatively more with the engine cold than it does in other circumstances. All of this is to provide the most efficient engine power with the least possible amount of fuel and exhaust emissions. The advanced spark also helps warm the combustion chamber temperature as quickly as possible.

Warm-Up

As the engine warms and the post-start period expires, additional enrichment is based on a combination of engine coolant temperature and load. An idle speed increase is applied to prevent stalling, improve driveability, and hasten warm-up. The idle speed increase occurs during the post-start mode and continues into the warm-up mode. As an added means of bringing the oxygen sensor and catalytic converter to operating temperature as quickly as possible, some versions of the Bosch

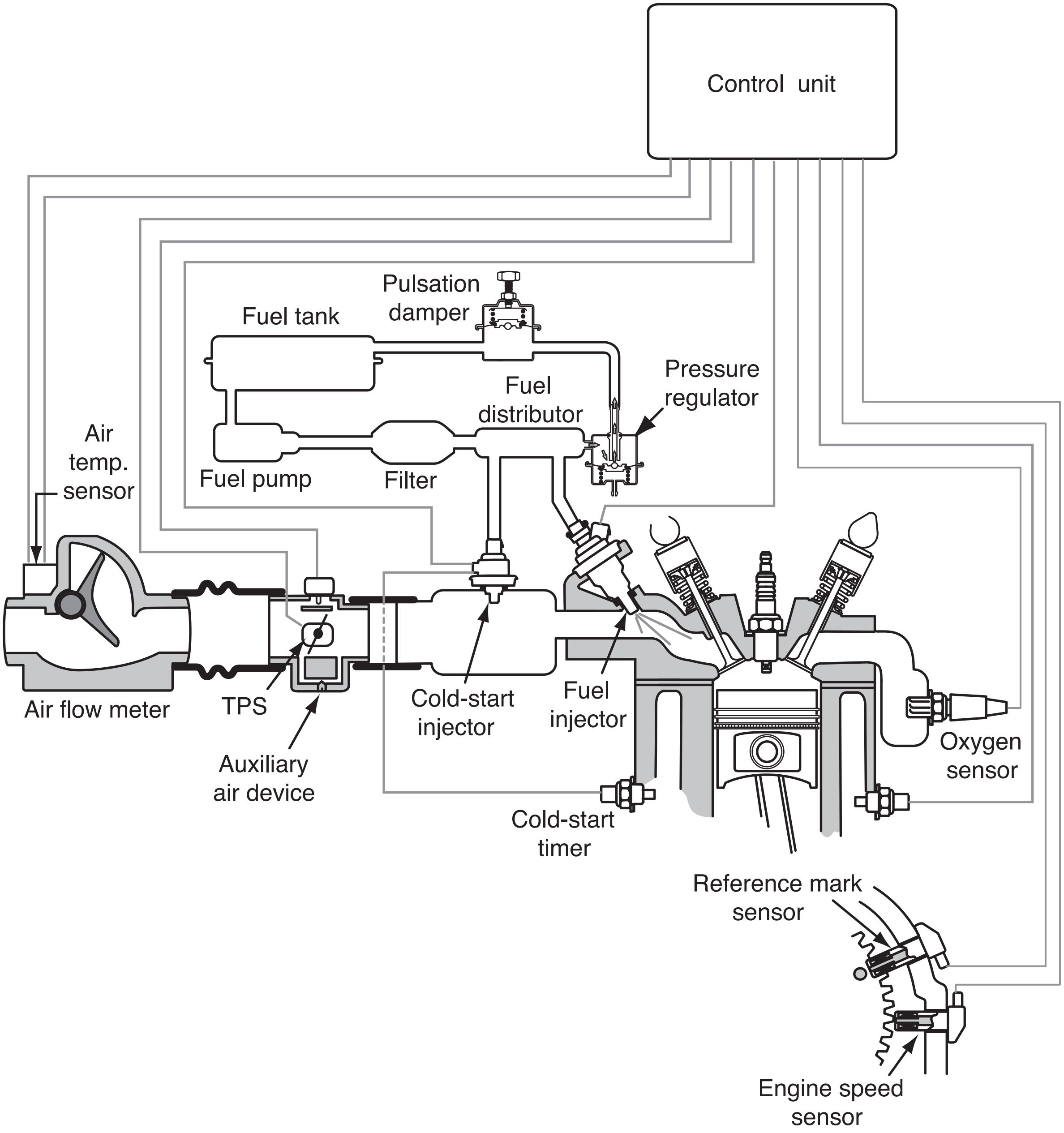


Figure 16–15 The Motronic system with cold-start injector.

Motronic system retard ignition timing during warm-up to make the exhaust gas somewhat hotter.

Acceleration

Whenever the driver quickly opens the throttle from an earlier fixed position, the ECU briefly enriches the mixture. This serves the same purpose as the accelerator pump in a carburetor and solves two problems: (1) air accelerates into the combustion chamber faster than the fuel might and (2) it is harder to get the fuel to vaporize in higher-pressure intake air. The degree of accelerator enrichment is affected by the engine coolant temperature.

Wide-Open Throttle

During wide-open throttle (WOT) operation, the ECU commands a fixed enriched air/fuel mixture. To avoid fuel quantity miscalculations from air flow sensor fluctuations, at this speed the fuel quantity is calculated based on engine speed. The objective of the mixture control strategy at WOT is to produce maximum engine torque without allowing detonation and physical damage. Emissions quality is not specifically optimized during WOT operation because WOT use is ordinarily restricted to driving conditions in which safety considerations (passing, perhaps) outweigh the disadvantages of momentary adverse emissions.

Deceleration (Overrun)

When the vehicle is decelerated, the ECU tapers the fuel delivery to zero and retards the ignition timing. Retarding the timing provides better engine braking and reduces the emission of hydrocarbons in the event there is still residual fuel on the intake port walls.

If the engine speed falls below a specified RPM or if the driver opens the throttle, the ECU returns fuel injection and spark advance to the appropriate level. This occurs gradually over a programmed number of engine revolutions rather than suddenly, for driveability and a smooth transition. On some Bosch systems, there is no fuel cutoff during deceleration, and in these systems a fuel-reduction program is used to avoid engine bucking and misfire, as well as high hydrocarbon emissions from misfires.

Closed Loop

The Bosch Motronic system, like other engine control systems, goes into closed loop once the engine coolant temperature and the oxygen sensor reach normal operating temperature. Bosch and other European manufacturers' technical literature frequently refers to the oxygen sensor as a "lambda sensor." While the oxygen sensors work the same way, a different description is used for the optimal air/fuel ratio. Until recently, European engineers identified the ideal ratio by the Greek letter **lambda.** In the United States, the ideal mixture has always been called the *stoichiometric ratio.* The two terms mean the same thing, and both oxygen sensors work the same.

INPUTS

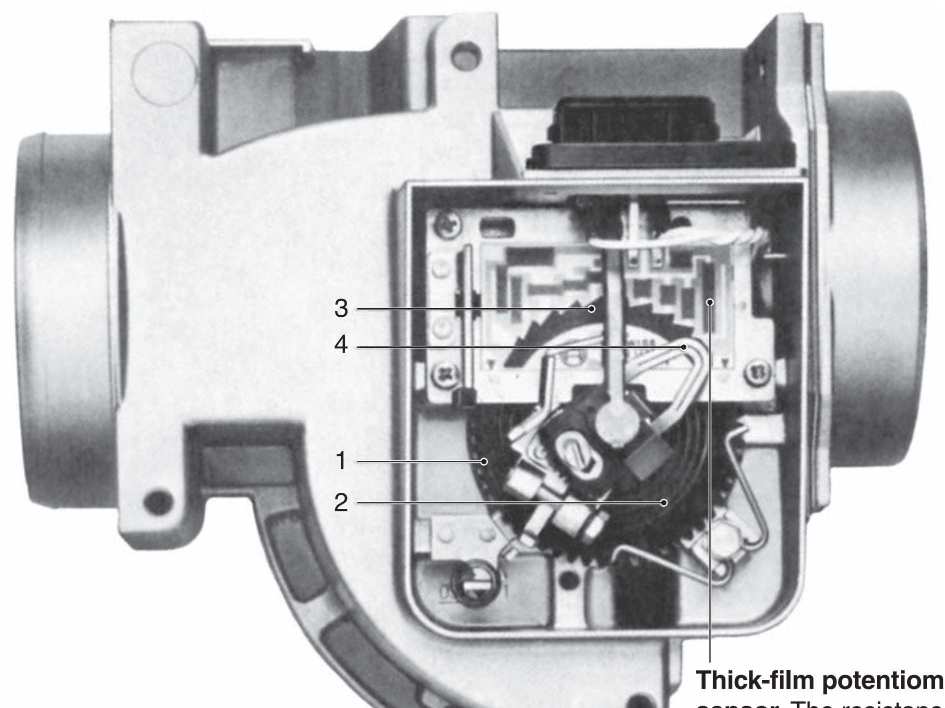
Air Flow Meter

The Bosch air flow meter used on the Motronic system is the same as described in the "Pulsed Systems" section of this chapter. The shaft of the sensor moves the wiper of a potentiometer designed to provide accurate voltage signals to the ECU (Figure 16–16). This unit is designed to provide consistent return signals in spite of aging and rapid changes in temperature.

The ECU can calculate the pulse width for each cylinder by comparing the information on crankshaft position and speed with air flow meter data. The injection then occurs during the appropriate cylinder's intake stroke.

Engine Speed Sensor

The ECU senses engine speed using an AC voltage pulse-generating device that uses



1 Ring gear for spring preload
2 Return spring
3 Potentiometer
4 Sliding contact

Thick-film potentiometer of the air flow sensor. The resistances can be identified as dark rectangular surfaces in the upper half of the figure. The resistive material is a ceramic-metal mixture that is burnt into the ceramic plate at a high temperature.

Figure 16–16 Air flow meter. (Reprinted with permission from Robert Bosch Corporation.)

the flywheel teeth as the pulse-triggering device (Figure 16–17).

Reference (Crankshaft Position) Sensor

The crankshaft position or reference sensor works like the engine speed sensor except that its trigger is usually a single pin on the flywheel (Figure 16–17). This sensor provides the ECU with information about crankshaft position.

Throttle Valve Switch

The throttle valve switch contains two sets of electrical contact points (Figure 16–18). Each set has a separate circuit and receives a reference voltage from the ECU. This circuit enables the

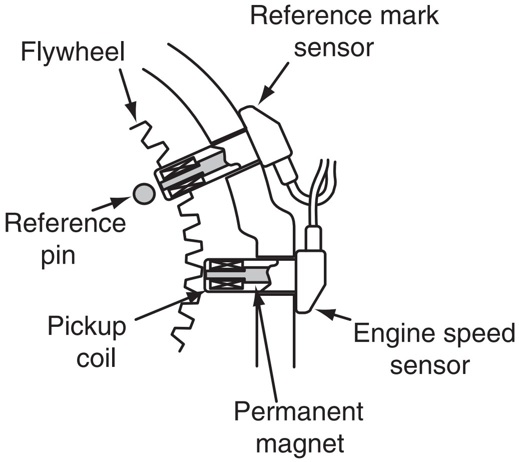
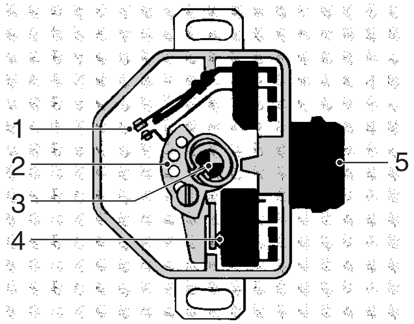


Figure 16–17 Engine speed and reference mark sensors.



1 Full-load contact
2 Switch guide
3 Throttle shaft
4 Idle contact
5 Electrical connection

Figure 16–18 Throttle valve switch. (Reprinted with permission from Robert Bosch Corporation.)

ECU to determine whether each of the switches is open or closed. When the throttle is closed, the idle contacts close, completing the circuit for that switch. During part-throttle operation (all normal driving modes), both switches are electrically open. At WOT, the full load contacts close, completing that switch's circuit. The ECU can thus determine three driving conditions from the one unit. The throttle valve switch (containing both switches) is attached to the end of the throttle shaft.

Coolant Temperature Sensor

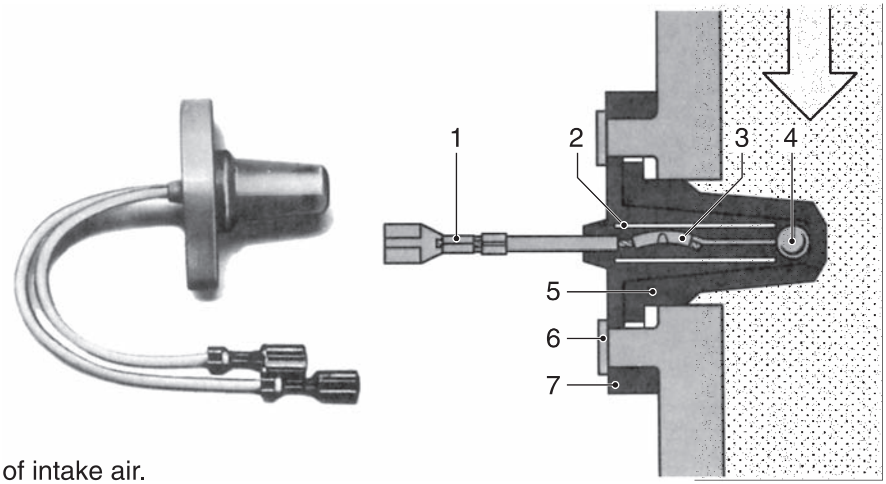
The engine coolant temperature (ECT) sensor is a thermistor bolted into the water jacket near the thermostat housing. Its operation is similar to those on domestic vehicles.

Air Temperature Sensor

The intake air temperature (IAT) sensor is a thermistor mounted in the intake opening of the air flow sensor (Figure 16–19). Its signal indicates the temperature of the intake air.

Oxygen Sensor (Lambda Sensor)

As previously explained, the earlier Bosch systems use oxygen sensors that work like familiar domestic units, but the literature describes them as *lambda* sensors, using the term commonly used by German engineers to indicate air/fuel stoichiometry.



1 Electrical connection
2 Insulation tube
3 Connector
4 NTC resistor
5 Housing
6 Rivet pin
7 Securing flange
Arrow denotes the direction of intake air.

Figure 16–19 Air temperature sensor. (Reprinted with permission from Robert Bosch Corporation.)

Lambda and Air/Fuel Ratio

German engineers have long used the Greek letter lambda (Λ) to represent a ratio reflecting the air/fuel ratio. The relationship lambda represents is:

Lambda = actual inducted air quantity ÷ theoretical air requirement

The theoretical air requirement is 14.7 units (by weight). If the actual air quantity used is 14.7, then lambda = 1. Using this method of expression, an air/fuel ratio richer than 14.7:1 is expressed as a number less than 1. For example, 0.9 is equivalent to a 13.23:1 air/fuel ratio (13.23/14.7 = 0.9). An air/fuel ratio leaner than 14.7:1 is expressed as a number greater than 1. For example, 1.03 is equivalent to a 15.14:1 air/fuel ratio (15.14/14.7 = 1.03).

Knock Sensor

The Bosch Motronic system uses a piezoelectric knock sensor (Figure 16–20). The sensor generates a voltage signal in response to most engine vibration frequencies, but the signal is strongest at frequencies resonant with detonation knock frequencies. At a vibration between 5 and 10 KHz, the ECU recognizes knock and begins retarding the spark. The knock sensor is located on the block between two cylinders. On some engines, particularly V-type engines, two knock sensors are used. Combined with the information the computer has about crankshaft position, this can identify the individual cylinder with knock, allowing the system to retard the ignition timing to that cylinder selectively (a feature only on later versions of the Motronic system).

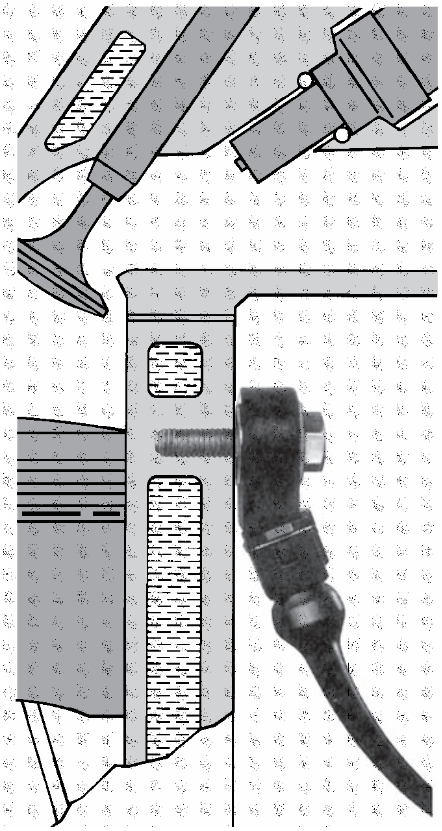


Figure 16–20 Knock sensor. (Reprinted with permission from Robert Bosch Corporation.)

Altitude Sensor

The altitude-sensing device, or barometric pressure sensor, is an aneroid unit attached to the wiper of a potentiometer. The aneroid assembly has a sealed pressure on the inside. When external pressure changes, the aneroid assembly expands or contracts accordingly. This movement moves the wiper on the potentiometer and sends a respective signal to the ECU. On most Bosch-equipped vehicles that utilized this sensor (those applications using a VAF meter), it was located in the air cleaner assembly.

Starter Signal

The cranking control circuit provides a signal to the ECU when the starter is being cranked.

Battery Voltage

A system voltage input from the vehicle's electrical system is provided to the ECU so it can monitor battery and charging system voltage.

OUTPUTS

In general, Motronic systems control the operation of the fuel injectors, the engine speed limiter, the fuel pump relay, ignition timing, and dwell. Specific vehicle manufacturers may incorporate other features designed for a particular car.

Injectors

The injectors used on Bosch systems are like those used in domestic-built multipoint fuel injection systems. In fact, domestic manufacturers have historically used Bosch injectors for their multipoint-injection systems.

The Bosch injectors are solenoid-operated, pintle-type valves. In open-loop operation, the ECU calculates pulse width based on engine load and engine speed; engine load is calculated from air flow and engine speed information. Figure 16–21 shows a three-dimensional graph or "map" correlating load, speed, and air/fuel ratio for a given engine application. Air/fuel ratio is expressed as lambda, which was explained previously, but the translation into more familiar domestic stoichiometric terms is straightforward.

This map is stored digitally in the ECU's read-only memory. It functions as the look-up table to determine pulse width. The arrows indicate increased load, speed, and richness. Each line intersection represents a relative value of the desired air/fuel ratio.

The ECU can, however, modify the pulse-width value represented by each line intersection in response to the following information:

- *Engine temperature.*
- *Throttle position* as indicated by the throttle switch. The ECU also employs a special mixture-richening pulse-width command at warm WOT to prevent combustion detonation.
- *Air density.* The air flow sensor input must be corrected at higher elevations to allow for the thinner air. This correction is made with input

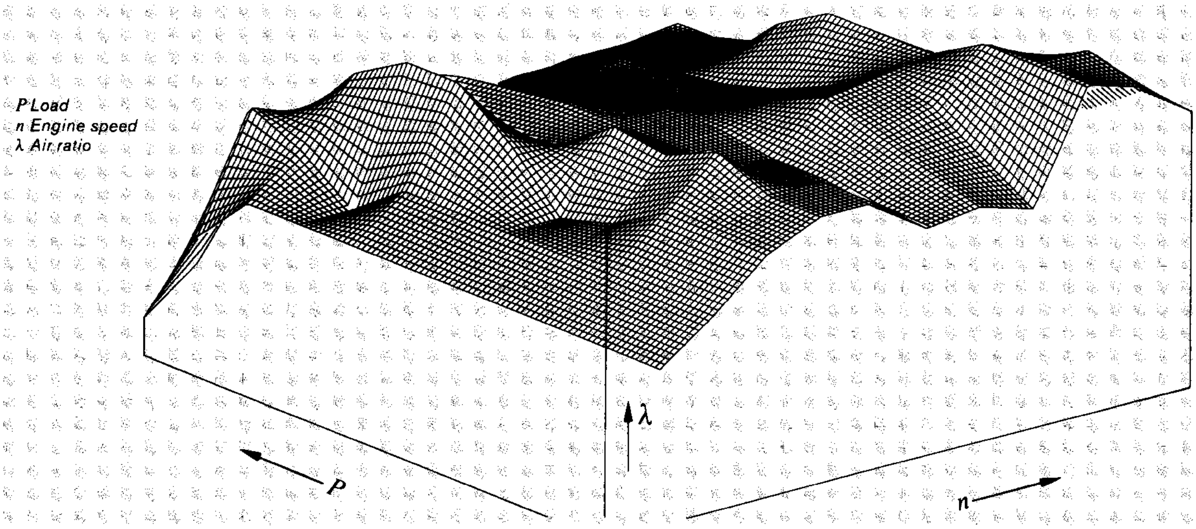


Figure 16–21 Pulse-width control map. (Reprinted with permission from Robert Bosch Corporation.)

Diagnostic & Service Tip

A common source of vacuum leaks, or "false air" as the Bosch literature sometimes calls it (because it does not go through the air flow meter), is around the injectors. The seal is usually a single O-ring. With heat and age, these O-rings can crack and cause vacuum leaks.

It is fairly common for an injector O-ring to leak after the injector is removed and reinstalled, even if it was not leaking air before, because the removal and replacement disturbed the seal. While it is not always necessary to replace O-ring seals when reinstalling an injector, they should be inspected carefully and replaced if necessary. Engine oil is generally regarded as the best O-ring installation lubricant, though at least one manufacturer favors 80-weight gear lubricant. Failure to inspect, and if necessary replace, the injector O-ring can allow a technician to build another new problem into a problem car.

Also, air-shrouded injectors are used by Volkswagen and several other carmakers on some of their models. Idle air does not pass through the regular intake channels but through a special idle air passage that leads to collars around individual injectors. This specially routed idle air keeps the air flow high where air meets fuel and improves vaporization of the fuel. This idle air shroud plumbing, however, constitutes another source of potential vacuum leaks. On early Volkswagen models, a plastic elbow near the idle air controller often developed cracks or splits that were very hard to spot.

from the air temperature sensor and, on the vehicles so equipped, the altitude sensor.

- *Battery voltage.* Just as on domestic fuel injection systems, the amount of fuel that flows through the injector is affected by the injector's response time, which is directly reflective of charging system voltage. The ECU can detect this voltage and modify the pulse width within a certain range to correct the fuel delivery.

Engine Governor. For each engine with a Bosch control system, there is a specific maximum allowable engine speed. If the engine speed exceeds that limit by more than 80 RPM, the ECU will shut off fuel injection until the engine falls to 80 RPM below the limit (Figure 16–22). This "red-line" limit is to prevent mechanical damage to the engine from over-revving. The system uses fuel cutoff rather than spark override to keep from dumping excessive hydrocarbons into the atmosphere.

Please note, however, that the engine governor function can only protect the engine from mechanical damage caused by powered over-revving. If a driver downshifts into a lower gear at high speed, the governor can shut off the fuel, but, driven by vehicle inertia, the engine could still spin fast enough to break something, probably a valve or connecting rod.

Limiting maximum engine speed $\boldsymbol{n}_o$ *by suppression of fuel-injection pulses.*

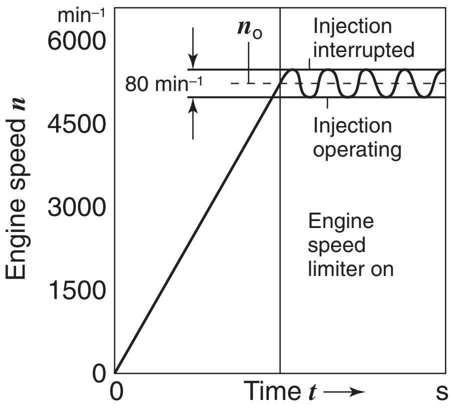


Figure 16–22 Engine speed governor. (Reprinted with permission from Robert Bosch Corporation.)

Fuel Pump Relay

As on most fuel injection systems, the fuel pump is indirectly controlled on Motronic systems through a fuel pump relay. Power is available at the relay whenever the ignition switch is turned on. The ECU then energizes or de-energizes the relay's coil to activate or shut off the fuel pump. If the engine does not turn at a minimum specified speed, the ECU will shut off the relay to reduce the risk of fire. As on many other fuel injection systems, the high-pressure fuel pump is located inside the fuel tank and is submerged in fuel. Earlier systems employed a fuel pump just outside the tank, on the line to the engine compartment and just ahead of the fuel filter (some have the filter in the engine compartment).

Fuel Pressure Regulator. The Bosch fuel pressure regulator, like most others, uses intake manifold absolute pressure to maintain a constant pressure differential between the fuel in the fuel rail and the air in the intake manifold (Figure 16–23).

Fuel Pressure Pulsation Damper. The pulsation damper, also shown in Figure 16–23, works to eliminate the noise of fuel pulses from the pump. While it looks much like the pressure regulator, it is not connected to manifold vacuum and functions as a surge accumulator to absorb the pressure pulses from the opening and closing of the injectors. The pulsation damper is in the return line downstream from the pressure regulator. The higher-pressure Bosch systems, as well as those on four-cylinder engines, are more likely

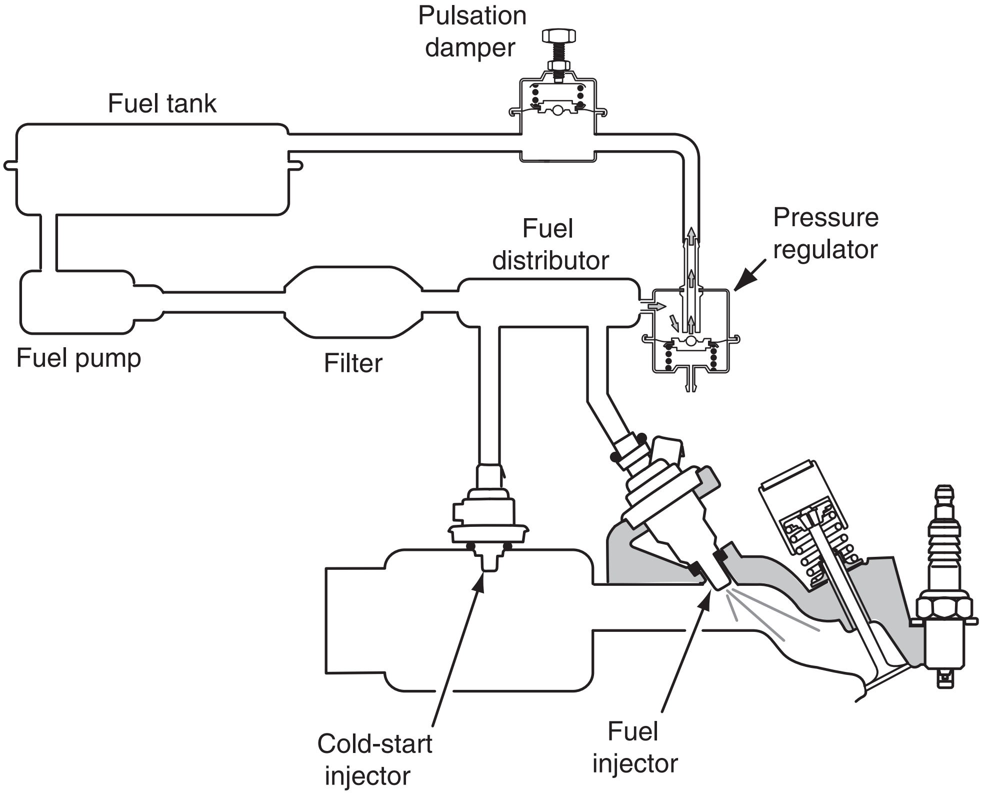


Figure 16–23 Fuel pressure regulator (right) and pulsation damper (left).

than the low-pressure systems or those on five-plus cylinder engines to use pressure dampers because the effects of the pulses are greater in them. Higher pressures are often preferred by carmakers because the fuel is more finely atomized under higher pressure, other things being equal.

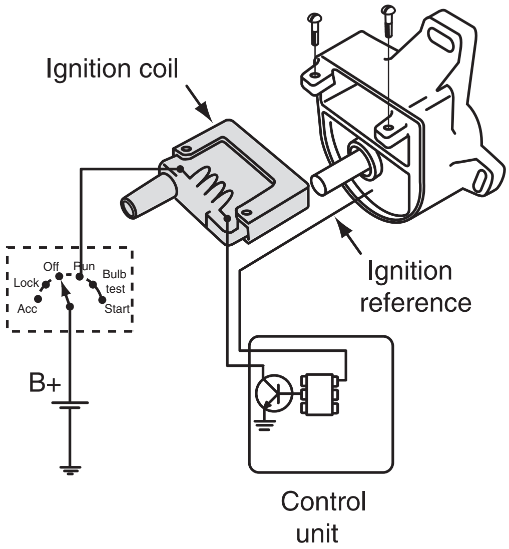


Figure 16–24 Ignition circuit.

Ignition Timing

The ECU operates the ignition coil by ground switching the primary windings (Figure 16–24). Like fuel injection pulse width, ignition timing is based on engine load and speed. Figure 16–25 shows a three-dimensional map of spark advance for one engine. Arrows point in the directions of increased load, speed, and spark timing advance. The line intersections represent the spark advance for all combinations of engine speed and load. These values are stored digitally as a look-up table in the ECU's read-only memory.

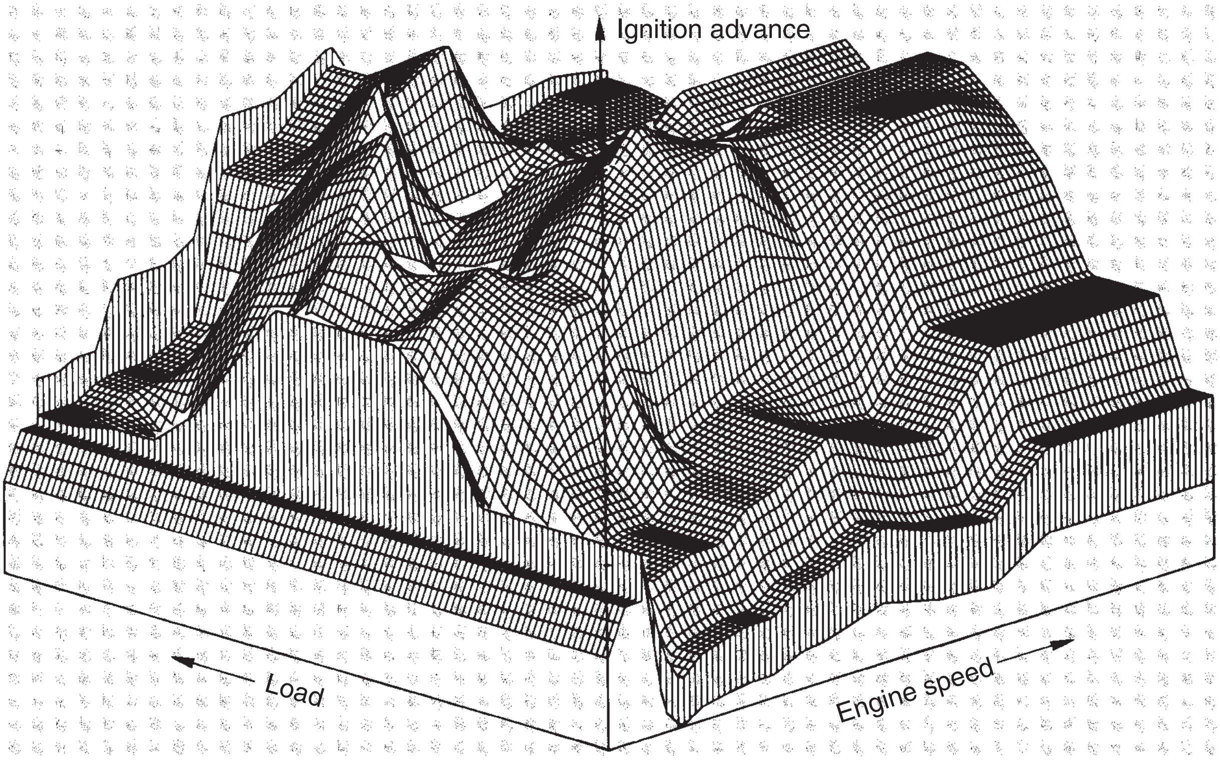


Figure 16–25 Ignition timing map. (Reprinted with permission from Robert Bosch Corporation.)

The ECU reviews sensor inputs and recalculates spark timing anew after each cylinder firing. The ECU can modify the values in the read-only map in response to inputs from:

- ECT sensor
- IAT sensor
- throttle position switch (during WOT operation, timing is set for maximum torque with retard applied only to prevent detonation)
- altitude sensor (if present)

The ECU modifies the spark advance according to the information from either the ECT sensor or the IAT sensor. This modification, of course, depends on driving conditions. At starting crank, timing depends entirely on engine speed and coolant temperature. At low cranking speeds and low temperatures, the timing is close to TDC. At higher cranking speeds and with warmer engines, the timing is only slightly advanced. With high cranking speed even at low temperature, timing is more advanced. Each of these combinations improves starting and post–start-up driveability.

Once the engine starts cold, timing is advanced significantly for a brief period to reduce the need for fuel enrichment. Once the engine is warm enough to reduce the likelihood of stalling, the ignition timing is retarded on some vehicles to speed up engine warm-up, even at the cost of lower delivered engine torque. Increased exhaust temperature helps warm the oxygen sensor and catalytic converter more quickly.

On earlier systems, during warm idle, ignition timing is used to control idle speed. With no additional load, transmission in neutral, and air conditioning off, the timing can be retarded slightly and still maintain the desired idle speed. This keeps combustion chamber surfaces hotter to reduce the production of unburned hydrocarbons. If there is a load, such as the transmission going into gear, the idle speed begins to slow. The ECU responds by advancing ignition timing enough to achieve more torque and bring the idle speed back to the desired speed. This saves opening the throttle and reduces fuel consumption. On applications with the rotary idle adjuster, idle air increases if advancing the spark timing alone is not enough to keep the idle speed at the desired setting.

At WOT, normal or higher engine coolant and/or intake air temperature cause the ECU to reduce spark timing at those load combinations where there is highest probability of spark knock. If at a specific load there is acceleration short of WOT, the ECU retards the existing spark advance and then gradually begins to restore it. This reduces both spark knock and the production of oxides of nitrogen.

Spark Knock Control

On earlier systems the spark knock control was separate from the Motronic unit. Later, it was incorporated into the ECU. The later versions, controlled by the computer, allow a more detailed control of spark advance. When the knock sensor indicates a detonation signal, the ECU recognizes the knock and immediately reduces spark advance until the knock disappears. Then it gradually re-advances timing toward the original value until the knock returns.

Dwell Control

The Motronic ECU manages ignition coil dwell in the same way as the General Motors HEI system. As engine speed increases, dwell increases to ensure complete magnetic saturation of the coil. The Bosch system also considers charging system voltage when calculating dwell.

Coil Peak Current Cutoff

If the ignition coil remains on with the engine stopped, both the ignition coil and the driver (transistor) in the ECU may overheat or burn out. To avoid this problem, the ECU automatically turns off the ignition coil any time engine RPM drops below a specified speed, usually about 30 RPM, well below a successful starting crank speed.

Idle Speed Control

Bosch Motronic systems use two different methods to control idle speed.

Auxiliary Air Device. On some applications, warm idle speed is controlled by an idle air bypass device in the idle air bypass passage. After a cold start and during warm-up, idle speed is increased by routing the air through an auxiliary air valve. A bimetallic strip inside the valve holds the valve open at low temperature (Figure 16–26). With the passage open, additional air bypasses the throttle blade. This air has, however, passed through the air flow sensor so the computer knows the correct amount of fuel to inject. In addition, once the ignition is turned on, voltage is applied to a heating element wrapped around the bimetallic strip. As the strip warms, it gradually closes the valve, blocking the flow of auxiliary air and slowing the idle as the engine warms. Once the engine is completely up to operating temperature, its own heat is enough to keep the valve closed.

Rotary Idle Control Valve. Other applications use the rotary idle control valve, controlled directly by the computer (Figure 16–27). This valve controls engine idle speed regardless of engine coolant temperature. At the end of an armature shaft, a rotary valve or slider valve can move in the idle air bypass (Figure 16–28). The DC electric motor has a permanent magnetic field and two armature windings. By controlling the voltage applied to the two windings, the ECU can rotate the armature incrementally and thus position the rotary valve to control idle air bypass. The ECU's memory has a programmed idle speed that it wants to maintain for any given engine coolant temperature. It first uses ignition timing to adjust idle speed; it then uses the rotary idle adjuster to bring idle speed to the desired RPM if the timing adjustments have been insufficient.

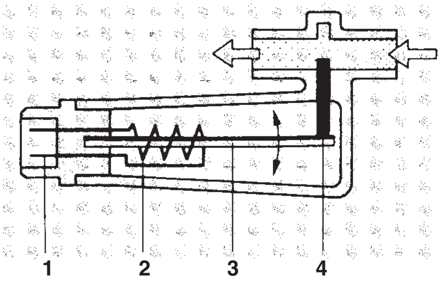


Figure 16–26 Auxiliary air bypass device schematic. (Reprinted with permission from Robert Bosch Corporation.)

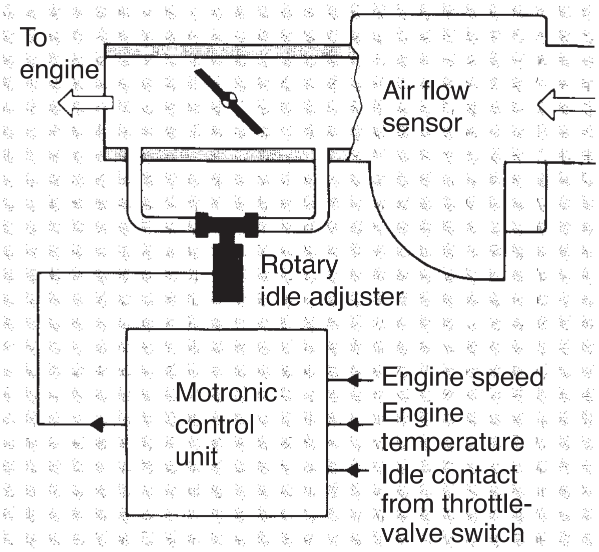


Figure 16–27 Rotary idle adjuster circuit. (Reprinted with permission from Robert Bosch Corporation.)

Turbo Boost Control

Bosch Motronic systems use a combination of spark retard and boost pressure reduction to control spark knock on turbocharged engines. Particularly on smaller engines, Bosch engineers feel reducing boost alone puts unnecessary limits on engine performance. They also find that using spark retard alone to control knock is a poor choice because it raises exhaust temperature, which can be threatening to the already high-temperature turbocharger turbine. Using a combination of both measures is the strategy

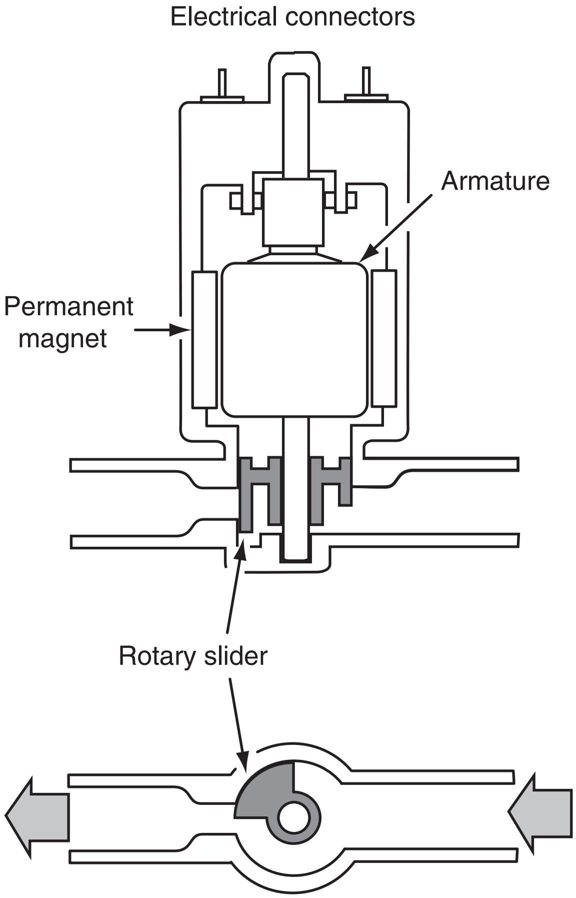


Figure 16–28 Rotary idle adjuster motor.

they prefer. Spark retard is the fastest measure (provided the knock is caused by spark timing and not by pre-ignition): It can be applied to the very next power stroke after the detection of knock. It takes several intake strokes even after the wastegate opens before the manifold pressure begins to come down because the turbocharger must slow and the intake air must start to cool. As boost pressure does come down, however, the Motronic system starts to re-advance the ignition timing to retain as much engine torque as possible. Later systems have the capability to retard ignition timing to individual cylinders, as described in previous chapters on domestic systems.

EGR Valve Control

Early European Bosch-equipped vehicles did not use EGR systems to control the production of oxides of nitrogen (NO_x) at high combustion temperatures. Instead, they used the reduction feature of the catalytic converter and the residual exhaust retained by the valve overlap. This method, however, does not allow the precise controls available with an electronically controlled EGR valve, so later versions employ EGR systems functionally similar to those used on most domestic-built systems.

Evaporative Emissions Control

Motronic system vehicles use an evaporative emissions system similar to those on domestic vehicles. Fuel vapors from the fuel tank are stored in a charcoal canister (Figure 16–29). Once the system goes into closed loop, the ECU activates a solenoid, opening a valve in the purge line connecting the canister to the intake manifold. As usual, precise mixture control then follows, using the oxygen sensor signal.

Electronic Transmission Control

Later versions of the Motronic system include sensors to indicate the transmission state. A vehicle speed sensor, transmission gear selection sensor, and kick-down sensor provide the ECU with this information. On some systems, the ECU controls the automatic transmission's hydraulic pressure and shift points (solenoid valves replacing traditional spool-type shift valves) (Figure 16–30). Shift point look-up tables (one for economy, one for performance, one for manual shifting) stored in the ECU's read-only memory provide optimum transmission shifting according to the programming look-up chart selected by the driver.

Smooth shifts with reduced clutch slip and wear are achieved, especially during WOT operation,

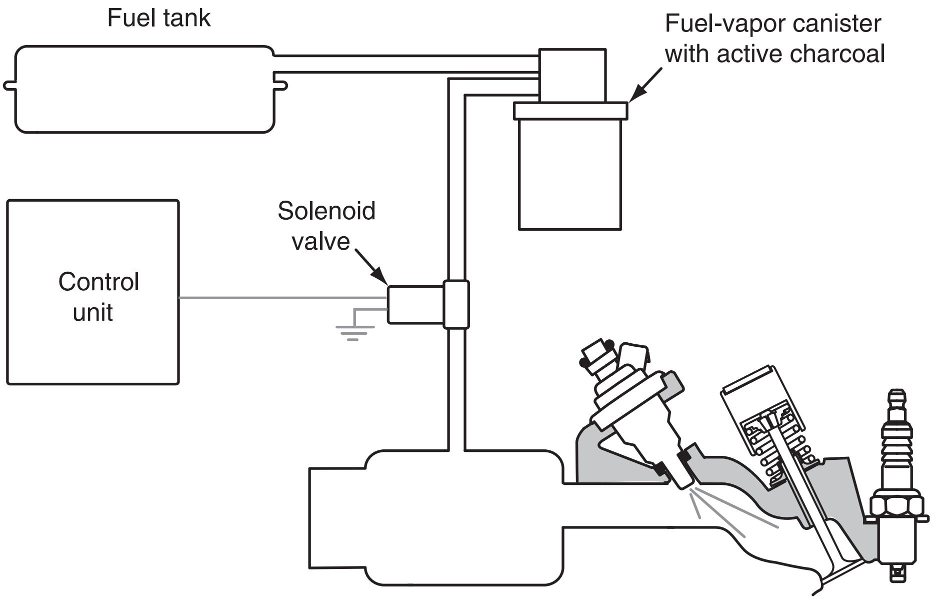


Figure 16–29 Evaporative emissions control system.

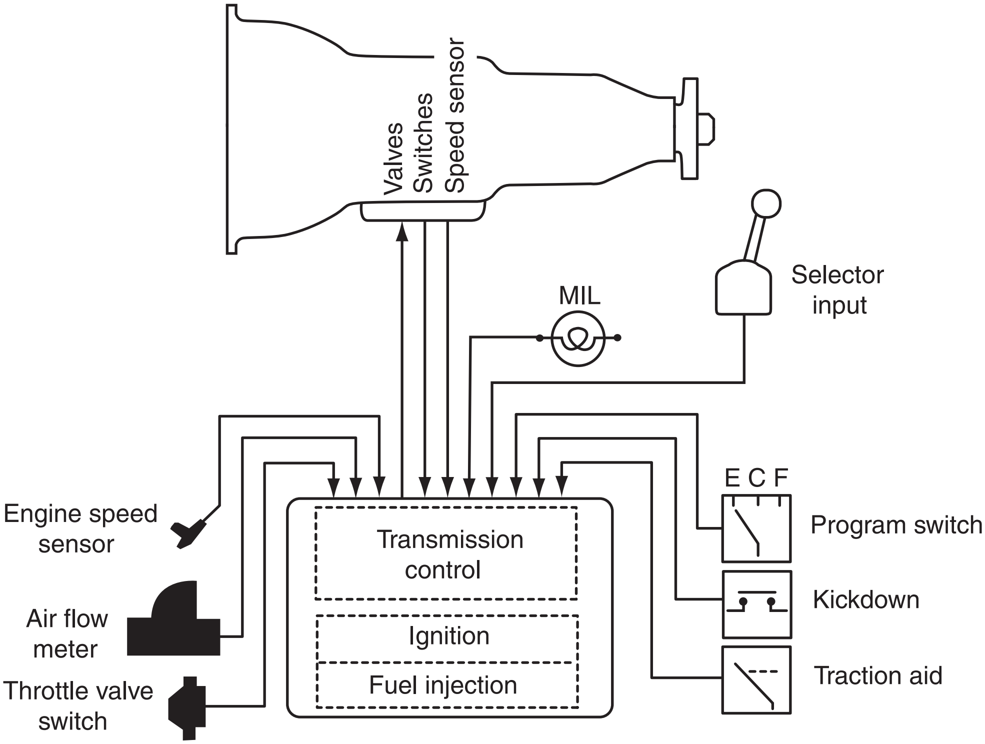


Figure 16–30 Electronic transmission control.

by momentarily retarding ignition timing to reduce engine torque output during the shift. Motronic transmission control can thus improve fuel economy, shift quality, transmission torque capacity, and expected transmission life.

Start-Stop Control

Another optional feature that can be added to a Motronic system is the start-stop control. This feature, incorporated on some European cars, is a predecessor of some modern systems (see the General Motors FAS and BAS systems in Chapter 12). This feature helps conserve fuel and reduce emissions. The Bosch feature was initially applied only on vehicles with manual transmissions.

The Bosch start-stop control uses a vehicle speed sensor, a clutch pedal position sensing switch, and a separate control module. If vehicle speed falls below about 1 mph with the clutch pedal depressed, the module signals the ECU, which shuts off the fuel. As long as the driver keeps the clutch pedal down, the module will activate the cranking circuit and fuel injection will resume as soon as the driver presses the accelerator. This system does not work until the engine is warm.

BOSCH OBD II UPDATE

Robert Bosch is the major European authority on the subject of computerized engine management systems, and its most highly evolved systems are in the Motronic family, used by Mercedes-Benz, Volkswagen, Volvo, and others. Motronic has always meant a combination of fuel and spark management since it was introduced in 1979. Now it has additional functions and numerical series designations like software.

The way the European carmakers adapt Motronic to satisfy OBD II regulations is interesting. In Mercedes-Benz C-class cars, for instance, the Motronic control module (M-B calls the system HFM-SFI for Hot Film Engine Management–Sequential Fuel Injection) is next to a proprietary diagnostic connector that is to be used with the company's own scan tool, which is used by dealership technicians. OBD II regulations are satisfied by a separate dedicated data link connector (DLC) that is electrically connected to the Motronic ECU, known under OBD II standards as the powertrain control module (PCM). The connection to the DLC uses a Controller Area Network (CAN) bus (see Chapter 9). This fulfills the EPA's legal requirements and sends emission-related data to a standardized OBD II DLC under the instrument panel for access with an aftermarket scan tool. The CAN bus also allows many other modules on a given vehicle to communicate with each other. Currently, some flagship Mercedes models have as many as 64 control modules and some flagship Audi models have between 70 and 130 control modules depending on how "loaded" the vehicle is. Most of these control modules are dedicated sub-modules, operating under a few major control modules.

In Motronic, just as in every other computerized engine management system regardless of country of origin, there is a comprehensive list of sensors, or operating-data acquisition devices, including a chassis accelerometer to differentiate between potholes and misfiring. This is different from the approach of other makers, such as GM, which uses signals from the ABS wheel speed sensors to indicate rough road surfaces.

The plausibility check of the mass air flow meter is a good example of a self-test. The computer makes continuous calculations from throttle angle and RPM to arrive at the probable injection duration (similar to the operation of a speed-density EFI system). Then it compares this value to that being obtained from the MAF sensor, and it stores a DTC if there is a large enough discrepancy.

A complex test procedure is required for the evaporative emissions system. The following is Volvo's means of performing it:

1. The canister valve is closed and the evaporative system (EVAP) valve is inhibited, which

should mean the tank is sealed and the pressure inside is stable. If pressure falls, a DTC for the EVAP valve is stored.

2. The canister valve is opened, venting the system. The EVAP valve starts to cycle and fresh air is drawn through the canister. Pressure in the tank should begin to fall slowly. A rapid drop will set a DTC for the canister shutoff valve.
3. With the canister valve closed, the EVAP continues to cycle, which should make tank pressure fall quickly. If it does not, the DTC will be for substantial leakage.
4. The EVAP valve is then closed, which should leave a vacuum in the tank. If this falls slowly, a small leak DTC is recorded.

✔ SYSTEM DIAGNOSIS AND SERVICE

The vehicle manufacturer establishes the diagnostic procedures for each vehicle, so procedures vary somewhat from one make to another. The diagnostic procedures here are representative of Bosch Motronic systems.

Troubleshooting Guide

The troubleshooting guide consists of a list of driveability complaints such as “Will Not Start Cold,” “Erratic Idle during Warm-Up,” and “Backfires.” Each complaint is accompanied by a list of possible causes. The possible causes should be checked either in the order of easiest to check or of most likely to cause the problem, based on the technician’s familiarity with the vehicle and the problem. It is important that all components or systems identified in the possible cause list for the complaints that are not part of the Motronic system are working properly before proceeding to the tests for the Motronic system.

Motronic Test Section

The service manual is likely to have a section that contains test procedures for each component of the Motronic system. The tests in this section should not be conducted until the engine is at normal operating temperature. When testing components and their circuits, remember that connections cause more problems than components.

SUMMARY

In this chapter we have learned about the history of Bosch fuel injection systems; we have considered the two mechanically distinct kinds of Bosch engine management systems: pulsed and continuous fuel injection. We have seen the differences between the K-Jetronic (continuous flow from the injectors), D-Jetronic (pulsed injectors controlled principally by the intake manifold pressure), L-Jetronic (fuel delivery determined by an air-door sensor), and Motronic (a complete engine management system, controlling mixture as well as ignition timing and other functions).

We have reviewed differences between today’s Motronic systems and the predecessor systems. The different operating conditions and how they work in the different operational modes were covered. We have seen several ways the ECU calculates engine load. We have considered the major input sources and output actuations, as well as the major functions. Finally, we have looked at diagnostic approaches.

▲ DIAGNOSTIC EXERCISE

A vehicle with a Motronic system comes into the shop, having failed an emissions test for high CO readings. The oxygen sensor is verified to be working correctly and is reporting the rich exhaust condition to the engine computer. To check the computer’s reaction to the oxygen sensor signal, the pulse width at the fuel injectors is measured. The pulse width on-time is low, about 1 ms at idle. What types of faults should be checked for?

Review Questions

1 The Bosch company has been involved with fuel injection since which of the following?
   A. 1920s
   B. 1950s
   C. 1970s
   D. 1980s

2 Technician A says that the fuel injectors in a Bosch pulsed injection system are electronically controlled by a computer. Technician B says that the fuel injectors in a Bosch continuous-injection system spray fuel continuously when the fuel distributor provides enough fuel pressure to the injectors. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

3 Technician A says that a Motronic system computer may control the fuel injection system, the spark management system, and certain other vehicle functions such as the automatic transmission. Technician B says that the D-Jetronic, K-Jetronic, KE-Jetronic, L-Jetronic, and LH-Jetronic systems are designed to control the fuel injection system only. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

4 Which of the following systems uses manifold pressure as the principal input for calculating engine load and, therefore, for determining how much fuel to inject?
   A. D-Jetronic
   B. L-Jetronic
   C. LH-Jetronic
   D. KE-Jetronic

5 Which of the following systems uses an air flow meter with a moveable door and potentiometer assembly as the principal input for calculating engine load and, therefore, for determining how much fuel to inject?
   A. D-Jetronic
   B. L-Jetronic
   C. LH-Jetronic
   D. KE-Jetronic

6 Which of the following systems uses a hot-wire air mass sensor as the principal input for calculating engine load and, therefore, for determining how much fuel to inject?
   A. D-Jetronic
   B. L-Jetronic
   C. LH-Jetronic
   D. KE-Jetronic

7 Technician A says that the main power relay in the Bosch Motronic system contains a diode used to protect the ECU against voltage surges and accidental polarity reversals. Technician B says that it is important to make sure that the Bosch Motronic ECU is properly mounted because it is designed to dissipate heat through its mounting brackets. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

8 Technician A says that the use of a cold-start fuel injector allows the fuel more time to vaporize while attempting to start a cold engine, thus making starting a little easier. Technician B says that a cold-start injector may form rust internally due to trapped moisture during periods of nonuse such as the summer months, and then may be plugged with contamination when cold weather returns, resulting in difficult cold starts. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician

9 Technician A says that the primary objective of the Bosch Motronic ECU during wide-open throttle operation is to keep engine emissions low. Technician B says that the Bosch Motronic ECU primarily calculates wide-open throttle fuel enrichment based on engine speed instead of air flow, due to the fluctuations

of the air flow sensor during heavy load conditions. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

10 Technician A says that some Bosch Motronic ECUs are programmed to reduce fuel delivery to zero during vehicle deceleration until engine speed falls below a specified RPM. Technician B says that a Bosch Motronic ECU is programmed to increase spark advance during vehicle deceleration until engine speed falls below a specified RPM. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

11 Technician A says that a Bosch Motronic system will not enter closed loop until the engine coolant and the oxygen sensor have both reached a specified operating temperature. Technician B says that a Bosch Motronic system is not a feedback system and operates in open loop under all driving conditions. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

12 What is a lambda sensor?

A. An Engine Coolant Temperature (ECT) sensor
B. An Intake Air Temperature (IAT) sensor
C. An oxygen sensor (O_2S)
D. An air flow meter or an air mass sensor

13 On a Bosch Motronic system, during which engine operating condition will the throttle valve switch have both switch contacts electrically open?

A. Idle
B. Part-throttle
C. Wide-open throttle
D. Only after engine shutdown

14 On a Bosch Motronic system, the ECU responds to the knock sensor by retarding spark timing when the knock sensor recognizes vibration that is between which of the following amounts?

A. 500 and 800 Hz
B. 2 and 4 kHz
C. 5 and 10 kHz
D. 12 and 16 kHz

15 Technician A says that the fuel injectors used on Bosch Motronic systems are similar to those used on General Motors and Ford vehicles because Bosch generally purchases its fuel injectors from General Motors and Ford. Technician B says that to prevent engine damage caused by over-revving, the Bosch Motronic ECU will disable the spark from the ignition system if engine RPM exceeds its programmed limit by more than 80 RPM. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

16 Why is the fuel pressure regulator on the Bosch Motronic system indexed to manifold absolute pressure?

A. So that it can keep the fuel rail pressure constant under all driving conditions.
B. So that it can maintain a constant pressure differential between the fuel in the fuel rail and the air in the intake manifold under all driving conditions.
C. So that it can vary the flow rate of the fuel injectors as a method of controlling the air/fuel ratio.
D. So that it can compensate for poor fuel delivery at wide-open throttle in the event that the throttle valve switch were to fail.

17 To improve ease of starting, a Bosch Motronic ECU slightly advances the spark timing during engine start during which of the following conditions?

A. At higher cranking speeds
B. At lower cranking speeds
C. With warmer engine temperature
D. Both A and C

18 On a Bosch fuel injected engine, the computer may control idle speed by all of the following methods *except* which of the following?

A. Adjusting ignition timing to control idle RPM
B. Using a DC motor to vary the physical position of the throttle plate
C. Using an auxiliary air valve with a bimetallic strip to control throttle bypass air
D. Using a DC motor-operated rotary control valve to control throttle bypass air

19 Technician A says that Bosch systems may retard spark timing to control spark knock on a turbocharged application. Technician B says that Bosch systems may reduce boost pressure to control spark knock on a turbocharged application. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

20 Technician A says that on some Bosch Motronic systems, the ECU controls transmission shift points through the use of solenoid valves that replace the traditional spool-type shift valves. Technician B says that on some Bosch Motronic systems, the ECU is able to smooth automatic transmission shifts and reduce clutch slip by momentarily retarding ignition timing, particularly during wide-open throttle operation. Who is correct?

A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

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Chapter 17

Asian Computer Control Systems

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

- ❑ Describe the sensors and actuators associated with Nissan's ECCS system.
- ❑ Describe the sensors and actuators associated with Toyota's TCCS system.
- ❑ Describe the sensors and actuators associated with Honda's PGM-FI system.
- ❑ Explain the differences between the Toyota VVT-i system and the Honda VTEC and VTEC-E systems.
- ❑ Understand the basic diagnostic concepts associated with OBD II diagnosis of these systems.

KEY TERMS

EGR Temperature Sensor
EVAP System Pressure Sensor
Front and Rear Oxygen Sensors
Fuel Temperature Sensor
Fuel Trim Compensation Factor
Hot-Film Air Mass Sensor
Linear Air/Fuel (LAF) Sensor
Two-Trip Malfunction Detection
Variable Cylinder Management (VCM)

In this chapter, we concentrate on Toyota, Nissan, and Honda computer control systems. Although these are not the only Asian cars imported to North America, they are representative and common, and their control systems are similar to many of the other Asian manufacturers' products. Because of the widespread use of shared components by Japanese manufacturers, an understanding of one company's systems often provides an understanding of the systems used by others. Furthermore, while there are Asian vehicles manufactured in Korea, these control systems are basically Japanese and the overwhelming number of such imports come unmodified (or simplified) from Japanese cars, so this is where our concentration will be. In each case, we consider only late-model vehicles, not the earlier and simpler systems. Many earlier vehicles used almost off-the-shelf Bosch controls or those built under Bosch license.

OBD II standardization of these systems has also minimized the differences among them as far as the technician is concerned: How the on-board computer reads its inputs, processes information, and controls outputs is essentially the same among different makes of vehicles. How a sensor or actuator works and how it should be pinpoint tested by a technician are also similar from one make to another. For example, the technician's ability to perform a sweep test on a throttle position sensor to check for glitches applies equally to all makes of vehicles. What is most often different from one make to another is the diagnostic program that has been programmed into a given PCM by the engineers. Prior to OBD II standards, the technician had to rely on the service manual for specific instructions on how to trigger the diagnostic procedures on a given vehicle. Under OBD II standards, the technician simply connects an OBD II–compliant scan tool to the diagnostic link connector (DLC) and then selects the appropriate function from the scan tool's menu.

NISSAN: ELECTRONIC CONCENTRATED CONTROL SYSTEM (ECCS)

Typical late-model Nissan ECCS applications use a **hot-film air mass sensor** as the principal input to the powertrain control module (PCM) to determine the fuel pulse width and spark advance. The PCM, of course, controls the fuel mixture and ignition based on information stored in its memory, as well as on inputs from all its other sensors. For a general overview of the entire system, see Figure 17–1.

Nissan uses both sequential injection and group injection, or simultaneous injection. The sequential mode injects fuel once every complete engine cycle (two crankshaft revolutions) during the corresponding cylinder's intake stroke. The group injection mode sprays all the injectors at once, twice per complete engine cycle. The group injection mode is used when the engine is starting, when the engine is in fail-safe mode, or when the camshaft position (CMP) sensor signal is lost and the engine is running on the crankshaft position (CKP) sensor signal alone.

The Nissan PCM does not keep ignition timing consistently at the edge of spark knock, using the knock sensor signal as a routine control input as with many other systems. Instead, the spark advance map is scaled to avoid knock under all but the extremes of load, engine temperature, and low fuel octane equivalency.

Besides normal conditions, the PCM also modifies ignition timing under special circumstances:

- during start-up
- during warm-up
- during idle
- when the engine is overheated
- during acceleration

The Nissan computer control system employs special fuel enrichment measures under many of the same specific circumstances:

- during warm-up
- during cranking and starting
- during acceleration
- when the engine is overheated
- during high load and high vehicle speed conditions

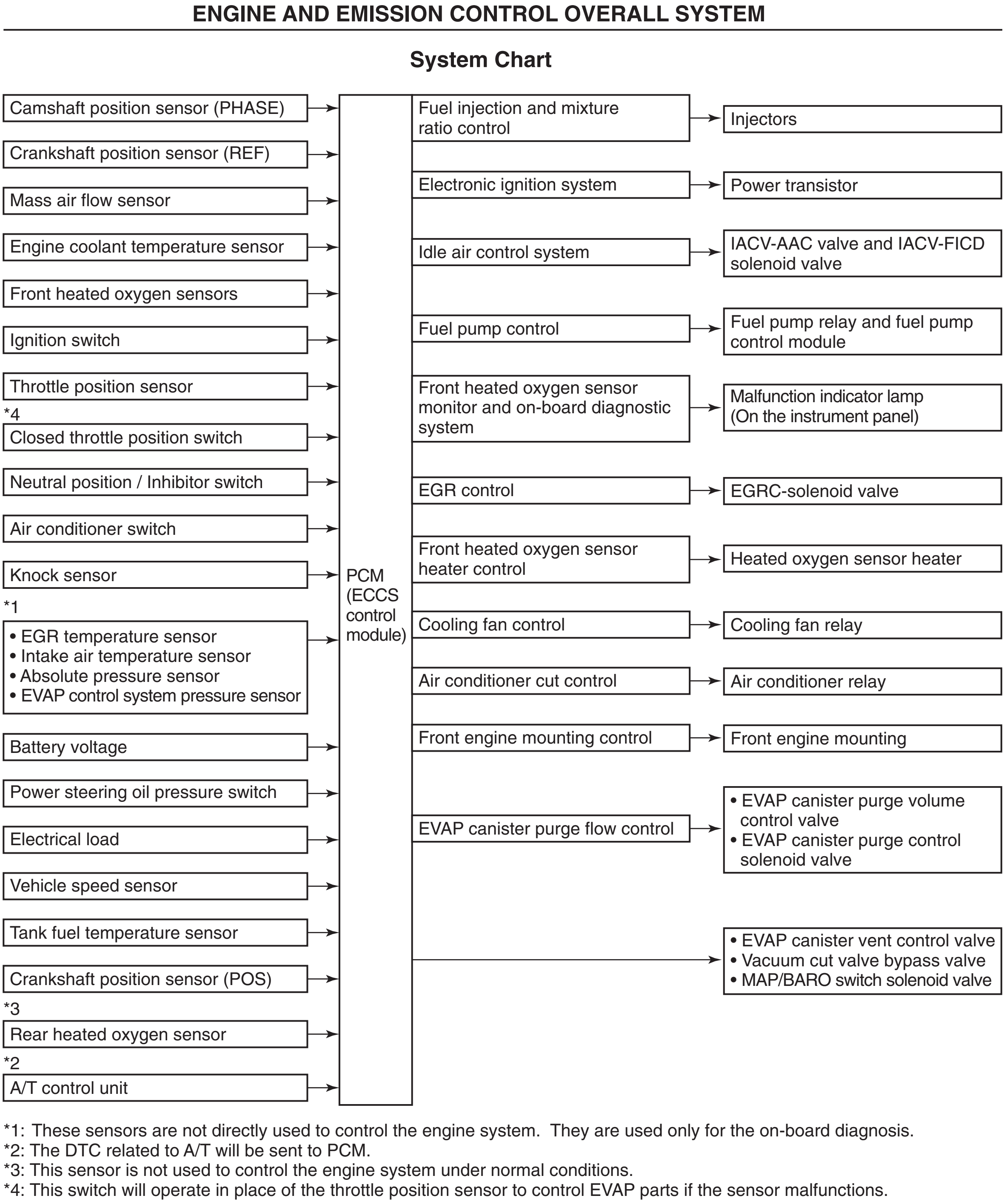
The system employs special lean fuel mixtures (including complete fuel shutoff in some cases) under other circumstances:

- during deceleration
- during low load, high vehicle speed conditions

Deceleration fuel cutoff will stop as engine speed falls below 2200 RPM with no load. Fuel cutoff does not begin unless the unloaded engine is above approximately 2700 RPM.

Mixture Ratio Self-Learning

The feedback control system employs a self-learning ability, similar to systems used on domestic cars. Like them, the Nissan system monitors the success of its pulse-width modification measures to keep the air/fuel mixture stoichiometric by input from the oxygen sensor. The measures used are called *fuel trim.* The PCM can modify its working copy of the hardwired mixture-to-pulse-width map depending on the results it sees from the oxygen sensor. It uses both a short-term and a long-term **fuel trim compensation factor,** similar to GM's fuel trim (integrator and block learn). The short-term factor corrects for temporary circumstances requiring fuel mixture adjustment; the long-term factor comes into play for gradual engine component wear and changes in the environment, such as altitude or seasonal climatic change.


ENGINE AND EMISSION CONTROL OVERALL SYSTEM

System Chart

Camshaft position sensor (PHASE)
Crankshaft position sensor (REF)
Mass air flow sensor
Engine coolant temperature sensor
Front heated oxygen sensors
Ignition switch
Throttle position sensor
*4
Closed throttle position switch
Neutral position / Inhibitor switch
Air conditioner switch
Knock sensor
*1
• EGR temperature sensor
• Intake air temperature sensor
• Absolute pressure sensor
• EVAP control system pressure sensor
Battery voltage
Power steering oil pressure switch
Electrical load
Vehicle speed sensor
Tank fuel temperature sensor
Crankshaft position sensor (POS)
*3
Rear heated oxygen sensor
*2
A/T control unit
PCM (ECCS control module)
Fuel injection and mixture ratio control
Injectors
Electronic ignition system
Power transistor
Idle air control system
IACV-AAC valve and IACV-FICD solenoid valve
Fuel pump control
Fuel pump relay and fuel pump control module
Front heated oxygen sensor monitor and on-board diagnostic system
Malfunction indicator lamp (On the instrument panel)
EGR control
EGRC-solenoid valve
Front heated oxygen sensor heater control
Heated oxygen sensor heater
Cooling fan control
Cooling fan relay
Air conditioner cut control
Air conditioner relay
Front engine mounting control
Front engine mounting
EVAP canister purge flow control
• EVAP canister purge volume control valve
• EVAP canister purge control solenoid valve
• EVAP canister vent control valve
• Vacuum cut valve bypass valve
• MAP/BARO switch solenoid valve

*1: These sensors are not directly used to control the engine system. They are used only for the on-board diagnosis.
*2: The DTC related to A/T will be sent to PCM.
*3: This sensor is not used to control the engine system under normal conditions.
*4: This switch will operate in place of the throttle position sensor to control EVAP parts if the sensor malfunctions.

Figure 17–1 Nissan system overview. (Courtesy of Nissan Motors.)

Air-Conditioning Cutout

To enhance engine performance and/or to preserve air-conditioner components, the air-conditioning compressor is automatically disengaged regardless of the control settings if these conditions exist:

- The throttle is fully open.
- During start-up cranking.
- At high engine speeds (to protect the compressor).

Evaporative Emissions System

The Nissan evaporative emissions system, like those of most other carmakers, uses a charcoal canister that stores fuel vapors from the tank to prevent their escape into the atmosphere. The system depends on the vapor pressure/vacuum relief valve in the fuel filler cap and the vapor recovery shutter in the filler tube. The PCM activates the EVAP canister purge volume control valve to operate the system under normal driving conditions. The fuel mixture pulse-width adjustments are made in response to oxygen sensor information since there is no way for the PCM to know how much fuel vapor, if any, is coming through the vapor canister.

INPUTS

Camshaft Position Sensor

The camshaft position (CMP) sensor (Figure 17–2) is in the front engine cover facing the camshaft sprocket. Information from the CMP sensor distinguishes which cylinder is at the firing position. The CMP sensor is a coil-and-magnet pulse generator: It consists of a permanent magnet wound in an electrical coil. When the gap between the camshaft sprocket and the magnet changes, the magnetic field changes, generating an AC voltage pulse in the sensor output line. The PCM uses the CMP signal to sequence the fuel injectors. As the engine is initially started and prior to the PCM receiving a CMP signal, all fuel injectors are simultaneously pulsed. Once the PCM receives its first CMP signal it begins pulsing the injectors sequentially.

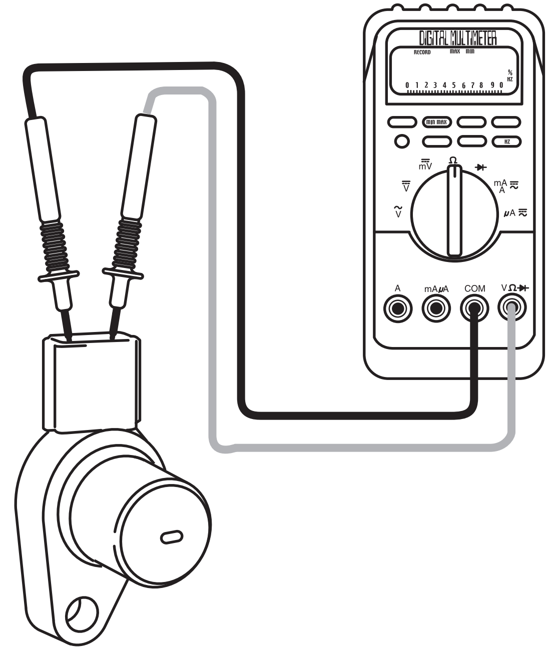


Figure 17–2 CMP sensor.

CMP sensors can be checked for shorts and opens with an ohmmeter, and for residual magnetism at the tip of the sensor with a strip of ferrous metal or a screwdriver tip.

Crankshaft Position Sensor

The crankshaft position (CKP) sensor (Figure 17–3) is on the upper oil pan facing the flywheel. It informs the PCM when each pair of cylinders is at top dead center (TDC). This sensor is a coil-and-magnet inductive signal generator producing a signal that varies in voltage with engine speed. Resistance through its coil should range between 470 and 570 Ω at room temperature.

The CKP sensor plays a familiar role in spark advance timing, fuel-injection timing, and the newest vehicles emissions monitoring. It is located on the flywheel end of the oil pan and signals one-degree changes in the flywheel position to the PCM. In later cars, the CKP sensor is the principal

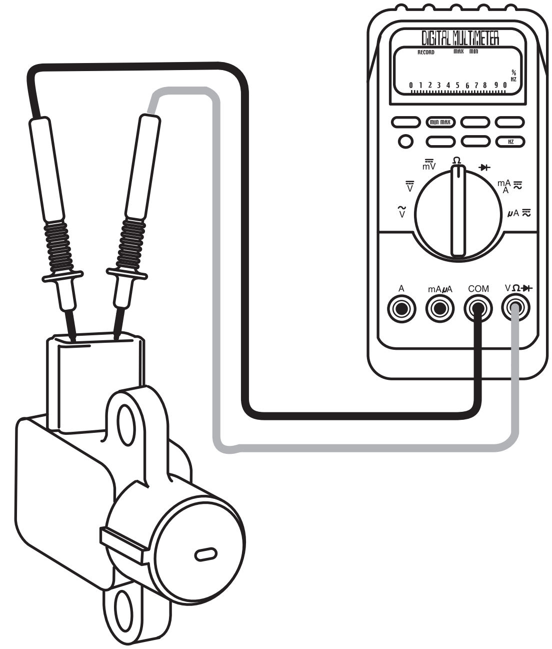


Figure 17–3 CKP sensor.

source of information about cylinder misfire. When a cylinder misfires, whether from spark, fuel, or mechanical problems, the engine slows down slightly at the point when that cylinder's power stroke should occur. At idle, this slowing is perceptible as rough running, but the CKP sensor can report the miss to the PCM even at higher speeds.

The emissions-related reason for tracking cylinder miss is that if the cylinder does not fire, it does not consume the fuel that entered with the intake stroke. The first consequence would be a considerable overheating of the catalytic converter from all the increased fuel and oxygen. The second consequence could be a failed catalytic converter, and the third would be the dumping of raw hydrocarbons into the air after the catalytic converter could no longer oxidize them.

Once the misfiring cylinder is identified by the CKP sensor, the PCM can then shut off the fuel injector to that cylinder. This is not, of course, a complete countermeasure because the oxygen is still pumped through the cylinder and into the exhaust. This means the oxygen sensor's reports will be inaccurate (overlean) and the PCM will drive the system rich. Because of this problem, this is one of the few circumstances when the PCM turns on the check engine light the first time the problem occurs, without waiting for it to recur on a subsequent trip.

Mass Air Flow Sensor

The hot-film air mass sensor is located in the intake air duct between the air filter and the throttle (Figure 17–4). It should indicate a signal voltage of below 1 V with the ignition on and the engine off and should show between 1.0 and 1.7 V at idle. With the engine running at higher speeds and under load, the signal voltage can rise to as much as 4.0 V. Because of the sensitivity of the sensor to disturbances in the air flow, a frequent check should be done to make sure no dust or foreign material is on or near the sensor.

Engine Coolant Temperature Sensor

Like other sensors, the ECT sensor modifies a reference signal from the PCM to correspond to the monitored parameter (Figure 17–5). The resistance of the thermistor in the sensor decreases as the engine temperature increases. Information from the ECT sensor plays a significant role in engine management because a richer mixture is needed for cooler temperatures to ensure there is enough vaporized fuel to burn. At operating temperatures, the system switches to a closed-loop control system, using the signal from the oxygen

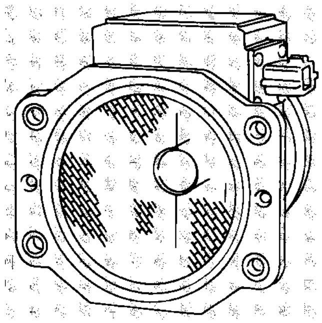


Figure 17–4 Mass air flow (MAF) sensor. (Courtesy of Nissan Motors.)

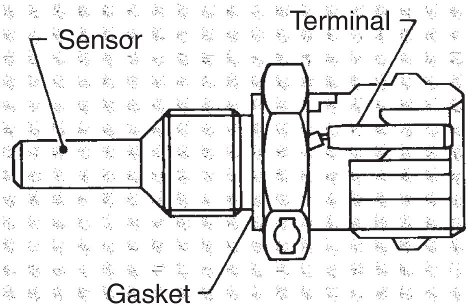


Figure 17–5 ECT sensor. (Courtesy of Nissan Motors.)

sensor. The ECT sensor, however, is critical to the determination of when the system goes into closed loop.

Front Heated Oxygen Sensors

Nissans use either a ceramic zirconia oxygen sensor (Figure 17–6) or a ceramic titania oxygen sensor. While either of these sensors is of the heated variety, the amplitude of the titania sensor's signal is slightly larger, with the signal switching between 0 V and 1 V (0 mV to 1000 mV), whereas the amplitude of the zirconia sensor operates within a range of 100 mV to 900 mV as the air/fuel ratio cycles from lean to rich and back again across the stoichiometric value.

The zirconia O_2 sensor *produces* a voltage in response to the exhaust gas oxygen content, similar to those used by other manufacturers. The titania O_2 sensor receives reference voltage and *modifies* the voltage signal returning to the computer through resistance changes in response to exhaust gas oxygen content (similar to an NTC thermistor circuit). The resistance of a titania sensor is less than 1000 Ω when the air/fuel ratio is rich and more than 20,000 Ω when the air/fuel ratio is lean.

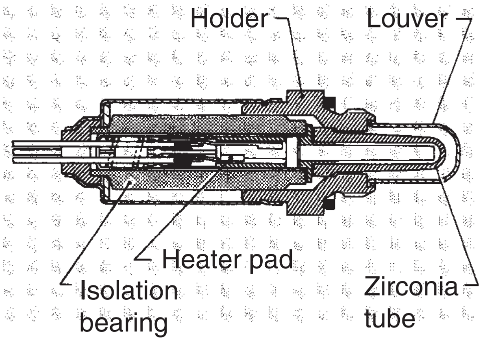


Figure 17–6 Heated oxygen sensor. (Courtesy of Nissan Motors.)

The zirconia sensor has a black wire (voltage signal out) and two white wires (heater positive and heater negative); the titania sensor has a black wire (voltage signal out), a red wire (reference voltage in and heater positive), and a white wire (heater negative). The titania sensor begins operating more quickly than the zirconia sensor following a cold engine start because it can begin responding to exhaust gas oxygen at a lower temperature.

The PCM gets the sensor's output signal and constantly readjusts the injector pulse width to correct the air/fuel mixture and keep the signal cycling. On V-type engines, two front oxygen sensors are used, one on each bank; the PCM controls the mixture delivered to each bank independently of that delivered to the other. The oxygen sensors are heated to bring the system to closed loop as quickly as possible and to prevent the system from falling out of closed loop should the vehicle idle for a long time.

Diagnostic & Service Tip

Very frequently the problem with an oxygen sensor is not that it has failed completely but that it has begun to respond too slowly to changes in the residual exhaust oxygen. Once this happens, the PCM will not be able to properly cycle the injector pulse width to keep the mixture stoichiometric. There is no specific number of cycles per unit of time that an oxygen sensor should register, but the newer systems should work more quickly than the older ones. If in doubt, monitor the signal cycling of a "known good" sensor and compare it to one you suspect.

Diagnostic & Service Tip

Oxygen sensors, particularly zirconia-based oxygen sensors, are relatively brittle and delicate components because of the ceramic element. If an oxygen sensor is dropped much more than a foot to a hard surface such as a concrete shop floor, it will probably sustain an invisible internal crack and will have to be replaced. An oxygen sensor is much more delicate than a spark plug as well as more expensive, so they should always be handled carefully.

Ignition Switch

When the ignition switch is turned on, the PCM becomes active and sends reference voltage to the sensors that require it. It also begins monitoring the return signals and prepares to energize the appropriate actuators.

Throttle Position Sensor

The PCM learns about accelerator pedal movement and position from the throttle position (TP) sensor (Figure 17–7). Like many other linear measurement sensors, the TP sensor receives a reference voltage from the PCM, routes it through a variable resistor, and returns a corresponding voltage to the PCM. Throttle position signals range from about 0.5 V to about 4.6 V from closed throttle to wide-open throttle.

Closed-Throttle Position Switch

The closed-throttle position switch (Figure 17–7) tells the PCM when the driver has removed his or her foot from the accelerator pedal. The PCM then knows to control the idle speed based on information from its other sensors. The closed-throttle switch is either on or off.

Park/Neutral Switch

The park/neutral switch allows the starter circuit to complete only with the transmission in one of these two gears. It also sends a signal to the PCM when the vehicle is in gear. This signal is used for idle control, spark timing, and sometimes fuel mixture.

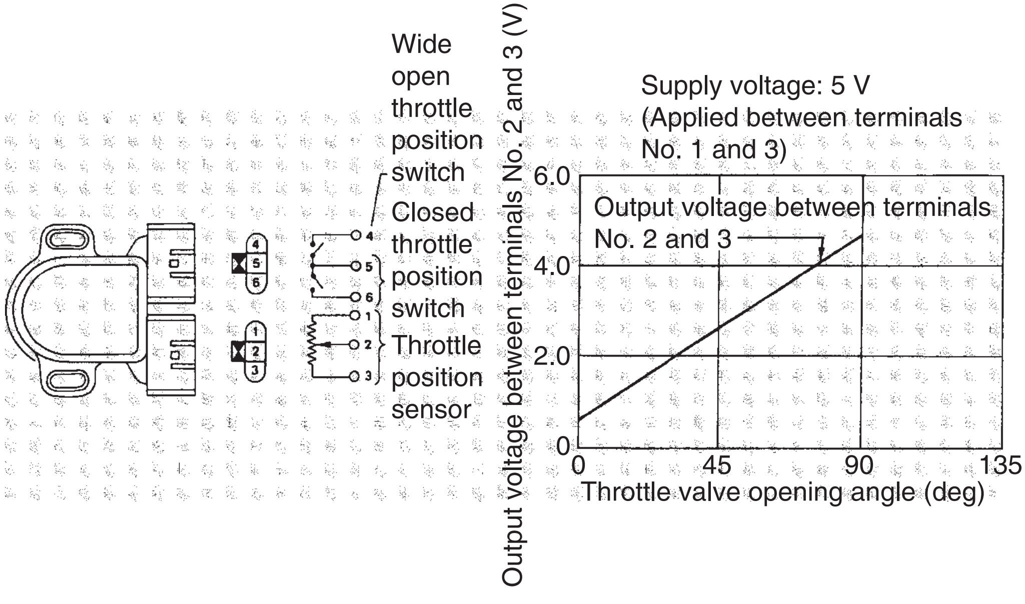

4
5
6
1
2
3
Wide open throttle position switch
Closed throttle position switch
Throttle position sensor
Output voltage between terminals No. 2 and 3 (V)
Supply voltage: 5 V (Applied between terminals No. 1 and 3)
Output voltage between terminals No. 2 and 3
6.0
4.0
2.0
0
0
45
90
135
Throttle valve opening angle (deg)

Figure 17–7 Throttle position sensor. (Courtesy of Nissan Motors.)

Air-Conditioner Switch

When the air conditioning is switched on, the PCM receives a signal that it uses to determine proper idle speed.

Knock Sensor

The Nissan knock sensor is a piezoelectric crystal type; it sends a voltage signal to the PCM in the event it sustains vibrations at a frequency characteristic of detonation. If the PCM receives such a signal, it retards ignition timing until the knock disappears. As already mentioned, the Nissan spark advance map is designed to prevent knock except under unusual fuel quality, load, or temperature conditions.

The knock sensor can be electrically inspected for shorts or opens. Nissan literature calls for an ohmmeter capable of measuring up to 10 MΩ. Like oxygen sensors, knock sensors are brittle and should not be reused if they have been dropped on a hard surface.

EGR Temperature Sensor

The **EGR temperature sensor** (Figure 17–8) reports changes in the EGR passage temperature. While this information does not directly control engine management functions, it is used for emissions diagnosis. If the PCM sees no signal or the wrong signal from the EGR temperature sensor, it indicates that insufficient exhaust gas recirculation is occurring through the EGR system, leading to excessive production of NO_x in the exhaust. The sensor is a thermistor, changing its resistance and thus the return signal with temperature changes.

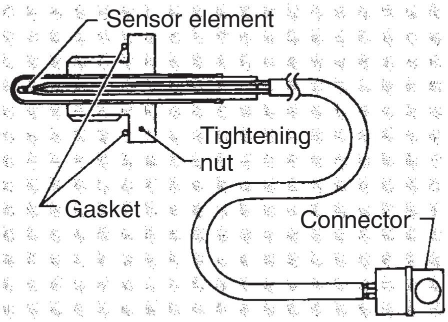


Figure 17–8 EGR temperature sensor. (Courtesy of Nissan Motors.)

Intake Air Temperature Sensor

The intake air temperature (IAT) sensor (Figure 17–9) mounts in the air cleaner housing and transmits a voltage signal corresponding to the IAT. The sensor uses a thermistor that is responsive to changes in temperature. As temperature rises, the resistance of the thermistor goes down.

Absolute Pressure Sensor

The Nissan manifold absolute pressure (MAP) sensor (Figure 17–10) connects to the

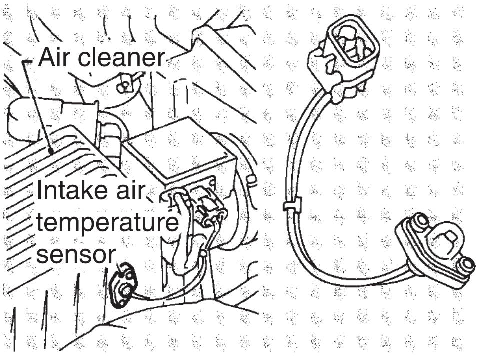


Figure 17–9 IAT sensor. (Courtesy of Nissan Motors.)

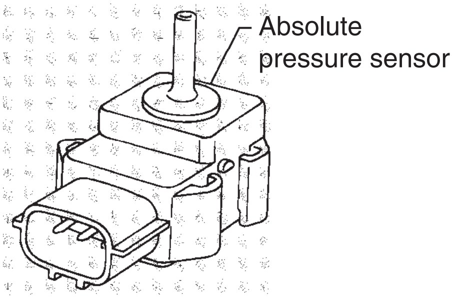


Figure 17–10 Absolute pressure sensor. (Courtesy of Nissan Motors.)

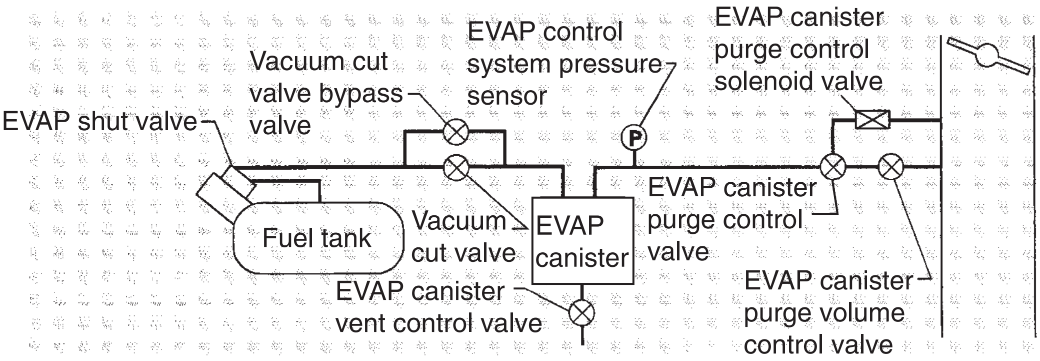

EVAP shut valve
Vacuum cut valve bypass valve
EVAP control system pressure sensor
P
EVAP canister purge control solenoid valve
Fuel tank
Vacuum cut valve
EVAP canister
EVAP canister purge control valve
EVAP canister vent control valve
EVAP canister purge volume control valve

Figure 17–11 Evaporative emissions system diagram. (Courtesy of Nissan Motors.)

map/baro switch solenoid through a hose. It detects both ambient pressure and intake manifold pressure. As the pressure rises, the voltage signal rises.

EVAP System Pressure Sensor

To monitor the effectiveness of the EVAP control system, the PCM receives a signal from the **EVAP system pressure sensor** (Figure 17–11). While this does not directly affect engine control functions, it does play a role in on-board emissions diagnosis. This sensor will indicate whether there is a leak in the vapor canister system.

This sensor cannot distinguish a leak in the system from a loose fuel filler cap, which will trigger the same trouble code and light the malfunction indicator lamp (MIL). Check for a properly functioning fuel filler cap first, including a pressure test of the cap, whenever this sensor indicates a problem.

Battery Voltage/Electrical Load

The PCM constantly monitors the voltage received from the battery and charging system and will illuminate the check engine light if it falls below proper voltages. This signal is used to modify the injector pulse width and the ignition coil dwell if system voltage falls below the standard charging system voltage.

Power Steering Oil Pressure Switch

The power steering oil pressure switch (Figure 17–12) is on the power steering high-pressure tube. When a power steering load occurs, it triggers this switch, signaling the PCM to increase the idle speed setting. This switch conducts battery voltage and can be checked for continuity with an ohmmeter.

Vehicle Speed Sensor

The vehicle speed sensor (Figure 17–13) is in the transaxle on the output shaft. Its pulse generator sends a signal corresponding to vehicle speed to the speedometer, which conveys the signal to

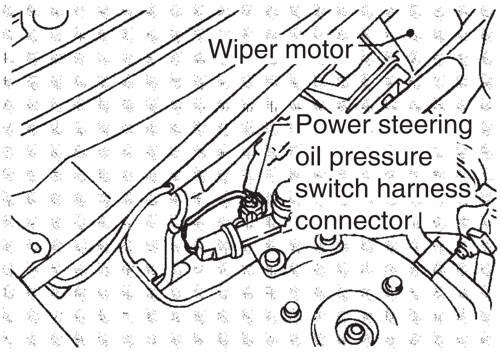


Figure 17–12 Power steering pressure switch. (Courtesy of Nissan Motors.)

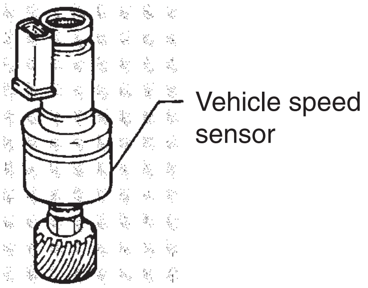


Figure 17–13 Vehicle speed sensor. (Courtesy of Nissan Motors.)

the PCM. This information is used for both fuel pulse width and ignition timing calculations.

Fuel Temperature Sensor

The system uses a thermistor-type **fuel temperature sensor** to monitor the temperature of the fuel in the tank. The sensor is accessible under the rear seat (Figure 17–14). The fuel temperature sensor receives a reference voltage from the PCM and returns to it a voltage signal corresponding to the temperature of the fuel, from 3.5 V when the fuel is at 68°F to 2.2 V when the fuel reaches 122°F. Information from this sensor indicates changes in fuel viscosity and its inclination to vapor lock. Nissan uses this sensor in conjunction with the EVAP pressure sensor. In addition to fuel temperature information, this sensor also helps the PCM determine when to run the fuel system leak detection software.

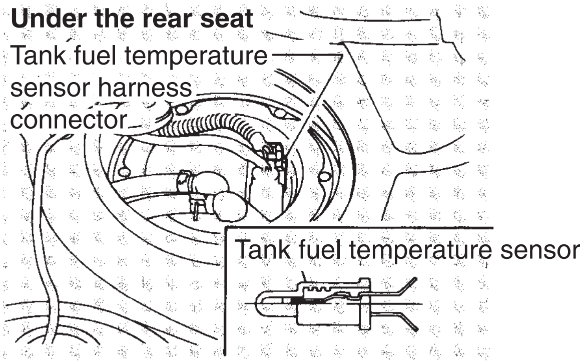

Under the rear seat
Tank fuel temperature sensor harness connector
Tank fuel temperature sensor

Figure 17–14 Tank fuel temperature sensor. (Courtesy of Nissan Motors.)

Rear Heated Oxygen Sensor

Nissan vehicles that conform to the OBD II regulations include a rear heated oxygen sensor. This sensor works in the same way as the front sensor or sensors but is used primarily to monitor the effectiveness of the catalytic converter. As long as the catalytic converter is working properly, the rear heated oxygen sensor's signal should remain almost flat or only slowly cycling over its output range. The PCM tracks the signal output and will set a code should the signal mirror that of the front sensor. If the front sensor fails, the PCM will use the rear sensor to control air/fuel mixture as closely as possible.

Automatic Transmission Diagnostic Communications Line

A communications link between the automatic transmission control unit and the engine control PCM conveys information related to transmission malfunctions. Any such information erased from the transmission unit must be separately erased from the engine control PCM.

OUTPUTS

Fuel Injectors

The multi-port fuel injectors are the Bosch type used on many vehicles. Activated by a constant power source and grounded through the PCM, each injector opens by lifting its pintle off the seat, allowing fuel to spray through the nozzle for a fixed amount of time, which is calculated by the PCM on the basis of all the system inputs.

IACV-AAC Valve and IACV-FICD Solenoid Valve

The idle air control valve–auxiliary air control (IACV-AAC) valve controls throttle bypass air, which determines the engine's idle speed

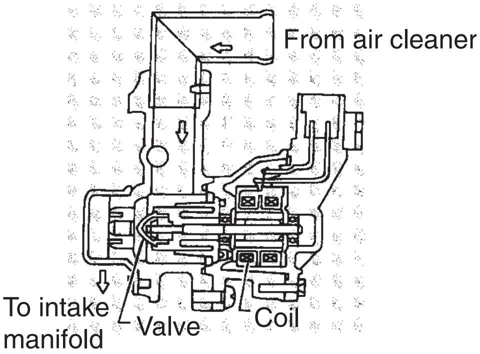


Figure 17–15 Idle air control valve. (Courtesy of Nissan Motors.)

(Figure 17–15). The PCM activates this component according to inputs from the ECT sensor, electric load sensor, air-conditioning switch, and power steering pressure switch. Once removed from the throttle body, the operation of this valve can be checked by cycling the ignition switch on and off to observe whether the valve shaft moves smoothly forward and backward in accordance with the ignition switch position. Removal and reinstallation of the valve should only be done with the ignition switch off.

The IACV-FICD solenoid combines with the IACV-AAC valve to constitute the idle air adjusting unit. The IACV-FICD solenoid is strictly an on-off solenoid moving a plunger in the air passage (Figure 17–16). It can be checked separately from the vehicle for smooth function.

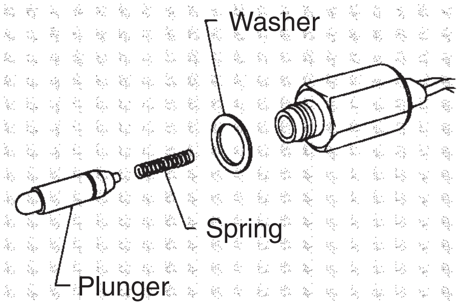


Figure 17–16 IACD-FICD solenoid valve. (Courtesy of Nissan Motors.)

Fuel Pump Relay and Fuel Pump Control Module

The fuel pump relay is activated for 1 second after the ignition switch is first turned on to pressurize the fuel system before starting the engine (Figure 17–17). The PCM will leave the relay energized as long as it receives input from the crankshaft position (CKP) sensor at the flywheel. The fuel pump control module adjusts voltage supplied to the fuel pump to control the amount of fuel flow (Figure 17–18). It reduces the voltage to approximately 9.5 V except in the following conditions:

- during engine start-up cranking
- when the engine coolant is below 45°F
- within 30 seconds after start-up with a warm engine
- under high load and high speed conditions

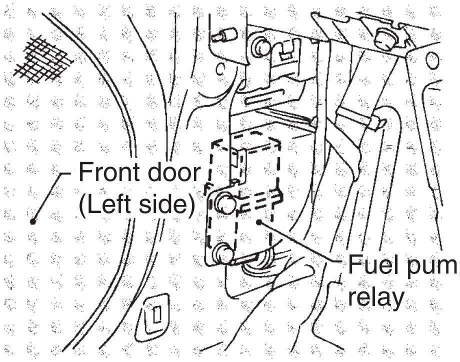


Figure 17–17 Fuel pump relay. (Courtesy of Nissan Motors.)

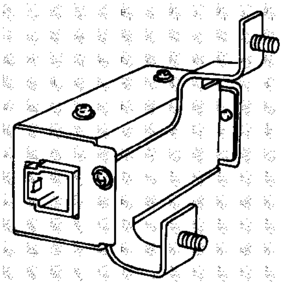


Figure 17–18 Fuel pump control module. (Courtesy of Nissan Motors.)

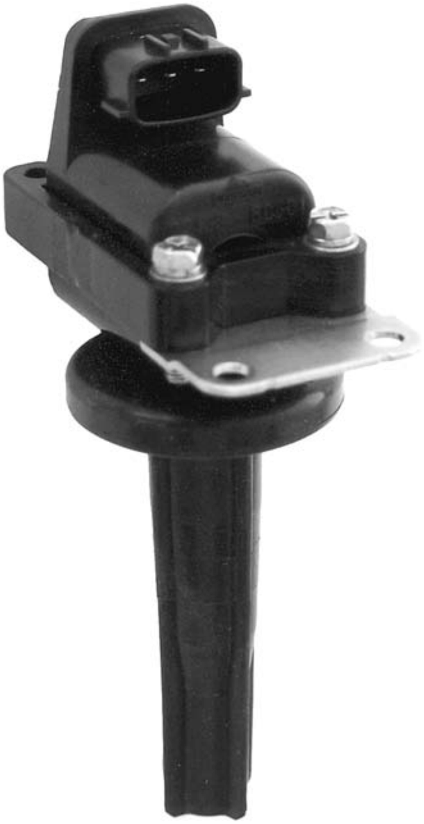


Figure 17–19 Nissan ignition coil.

Ignition Coil Power Transistor

Late-model Nissans use one coil per cylinder in a direct ignition system (Figure 17–19). If a bad coil is suspected, moving the coil from one cylinder to another to see whether the cylinder miss moves with it is the accepted technique. No internal repairs are possible; replacement is the only service.

Malfunction Indicator Lamp

The PCM turns on the MIL when it detects a fault in one of the engine's control or actuator circuits. Most malfunctions will have to occur in two successive trips before the PCM will turn on the MIL, but certain malfunctions that represent either failure of the engine to run properly or a risk of damage to a component will trigger the MIL the first time the problem is encountered. See the service manual to determine which problems fall into which category for specific models and years.

EGR Solenoid Valve

The EGR solenoid works in response to signals from the PCM. When the PCM grounds the circuit, the coil in the solenoid is energized and a plunger moves to cut the vacuum signal from the throttle body to the EGR valve. When the PCM sends an off signal, vacuum passes through the solenoid valve to the EGR valve. The system is thus designed to be fail-safe, with the EGR valve responding to manifold vacuum.

The functioning of the EGR valve is monitored by the EGR temperature sensor (Figure 17–8). The PCM can distinguish between EGR flow when there should be none and no EGR flow when there should be some by this temperature sensor, which sets different codes depending on which condition it detects.

The EGR valve can also be checked manually. If it does not move smoothly, it may have mechanical problems.

Fuel Pump Pressure

Fuel pump pressure with zero vacuum at the MAP sensor should be approximately 43 psi. At idle, the fuel pressure should read approximately 34 psi.

Fast Idle Cam

Instead of a stepper motor, some Nissans use a fast idle cam on the throttle linkage. The fast idle cam works by a thermostatically heated spring.

Oxygen Sensor Heaters

To ensure that the engine control system can go into closed loop as soon as possible, both the

front and rear oxygen sensors include heater circuits to get them to operating temperature as quickly as possible. The PCM will store different trouble codes for a failure of the heater circuit or for a failure of the oxygen sensor output circuit.

Cooling Fan Relay

The engine control PCM operates the radiator cooling fans through a relay depending on the engine coolant temperature, vehicle speed, and whether the air conditioner is turned on. There are two fan speeds available to the PCM. There are also differences in the fan speed maps for cars built for the California market, though the rest of the cooling system is the same.

Air-Conditioner Relay

When the air conditioner is turned on, the A/C relay provides the engine control PCM with a signal used to modify control of the idle speed.

Front Engine Mount Control

To keep the engine vibration to a minimum, the engine control system also electrically varies the dampening effect of the front engine mount. The mount is in a soft setting when the engine is idling and in a firm setting when the engine is doing work, moving the vehicle under load.

EVAP System Controls

The late-model Nissans use a more complex evaporative control system, storing fuel vapors in a charcoal canister as has been done for many years, but with a more complex set of controls and monitoring measures. Refer to Figure 17–11 under the “Inputs” section for a complete system diagram. The basic actuator is the EVAP canister purge control valve (Figure 17–20). When the PCM sends an off signal to the control solenoid valve, the vacuum between the intake manifold and the EVAP canister purge control valve is shut off. The EVAP canister purge volume control valve controls the passage of vapors from the EVAP canister purge control valve to the intake manifold (Figure 17–21). The system includes, as was described under the “Inputs” section in this chapter, an EVAP control system pressure sensor (Figure 17–11) intended to detect leaks in the system or a faulty, loose, or missing fuel filler cap. While the EVAP control system differs somewhat from one year to the next and from one model to another, fundamentally they all work the same way, storing fuel vapors in the charcoal canister until the engine, running in closed loop, can vent the canister into the intake manifold and burn the stored vapors. Corrections to the fuel mixture, as required by the variable concentration of fuel vapors entering the engine, are made on the basis of input from the oxygen sensor feedback control system.

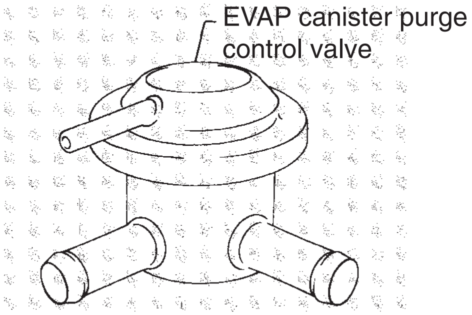


Figure 17–20 EVAP canister purge control valve. (Courtesy of Nissan Motors.)

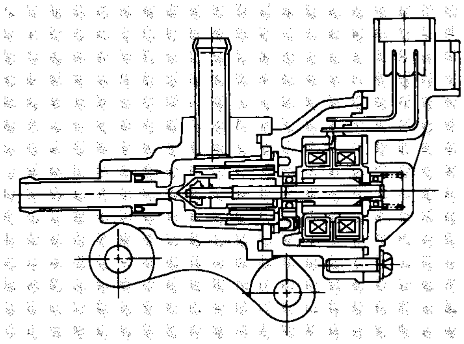


Figure 17–21 EVAP canister purge volume control valve. (Courtesy of Nissan Motors.)

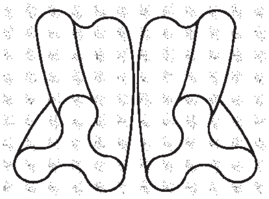


Figure 17–22 Nissan three-lobe rotor supercharger.

Nissan Supercharger

The Nissan Frontier pickup truck 3.3-L SOHC V6 engine introduced a roots-type three-lobe supercharger, built by Eaton, for the 2001 model year. It mounts to the stock 3.3-L intake manifold. It is limited to 6 pounds of boost (Figure 17–22).

The engine produces 210 horsepower with 245 ft.-lbs. of torque. A bypass valve diverts the air back into the supercharger during normal driving. The fuel pump flow rate has been increased by 80 percent to meet wide-open throttle demands. The injector flow rate also has been adjusted accordingly. This increased performance has been achieved with only a 10 percent reduction in fuel economy (Figure 17–23).

Diagnostic & Service Tip

With one coil per cylinder buried in the valve cover on late-model vehicles, it is somewhat more difficult to get spark advance and engine speed information without special Nissan tools. Nonetheless, you can remove the coil from the number one cylinder, attach an extension spark plug cable and test with conventional equipment. Many technicians use a similar technique on the GM Quad-4 engine.

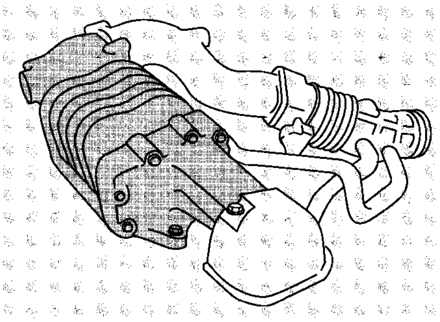


Figure 17–23 Supercharger system.

Nissan Intake Manifold Swirl Control System

The 2001 Nissan Sentra intake manifold has a door in each runner. All doors are mounted on a single shaft. The doors have two positions: rest and fully open (Figure 17–24).

When the door in the runner of the intake manifold is in the rest position, the intake manifold passageway is partially restricted, causing the moving air stream to swirl and increasing air velocity. The increased air velocity improves

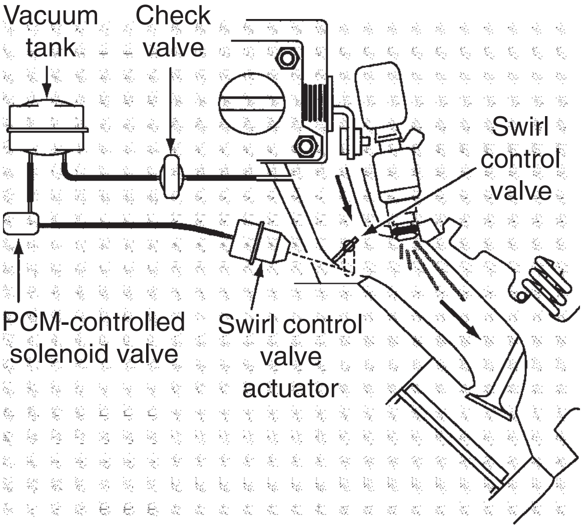
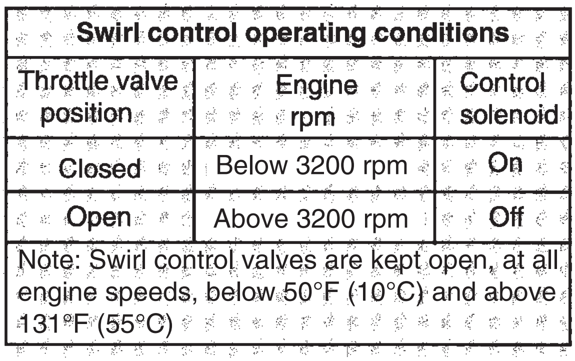


Figure 17–24 Nissan intake manifold swirl control system.



Swirl control operating conditions		
Throttle valve position	Engine rpm	Control solenoid
Closed	Below 3200 rpm	On
Open	Above 3200 rpm	Off
Note: Swirl control valves are kept open, at all engine speeds, below 50°F (10°C) and above 131°F (55°C)		

Figure 17–25 Nissan swirl control system operating conditions.

injected fuel vaporization. The doors are at rest at idle and during low engine speed. At higher engine speed, a single vacuum diaphragm opens the swirl control valves. The PCM turns a swirl control solenoid on or off to apply vacuum to the diaphragm. The restriction in the manifold runner is eliminated when the doors are wide open, improving intake efficiency (Figure 17–25).

Nissan Air-Cleaning Radiator

The California model of the Nissan Sentra is equipped with a new air-cleaning radiator to meet that state's Super Low Emission Vehicle (SULEV) rating. The radiator fins are coated with a special material that converts ozone molecules (O_3) into oxygen (O_2). When the driver drives the vehicle down the street, the cooling fan pulls dirty polluted air into and through the radiator fins. At normal operating temperature, the radiator coating acts as a catalytic converter, cleaning the air before it leaves the radiator. This radiator is not available in all parts of the country at this time.

✔ SYSTEM DIAGNOSIS AND SERVICE

Late-model vehicles include the OBD II standardized diagnostic system. In addition, they have retained the earlier Nissan self-diagnostics. This older system uses a screwdriver-actuated potentiometer in the PCM itself (ordinarily under the front passenger seat, but behind the instrument panel near the glove box on newer vehicles), displaying trouble codes either by flashes of the MIL or, on the earliest systems, by flashing lights on the PCM itself. The older systems, of course, are simpler, rely on fewer inputs and outputs, and provide less information for diagnosis. Check the shop manual for the specific information corresponding to the model and year of the vehicle you are working on.

Nissans use a **two-trip malfunction detection** logic; that is, for most component circuit failures the PCM stores a fault on the first trip in which it is detected and turns on the MIL if it recurs on the next trip (a trip is defined as an engine start-up, followed by enough driving to bring the engine to operating feedback control system condition). There are several different ways to erase stored faults in Nissan systems, including using the PCM's potentiometer to switch from Test Mode II to Mode I or using the scan tool, so read the manual for the specific car before you perform these tests. Disconnecting the battery erases the codes (as well as the self-learning data), but it can take as long as 24 hours of disconnection before the energy stored in the capacitors discharges fully.

TOYOTA COMPUTER-CONTROLLED SYSTEM (TCCS)

As an example of a TCCS, we look at the 1MZ-FE V6 engine in the late-model Toyota Camry. Other systems are similar, with appropriate modifications for engine type and vehicle style.

The Toyota system uses a mass air flow (MAF) sensor to determine how much fuel to inject at a given engine condition. The six fuel injectors are sequentially operated in the firing order of the engine. Spark is delivered through individual coils at each spark plug, similar to the Nissan system described earlier in this chapter.

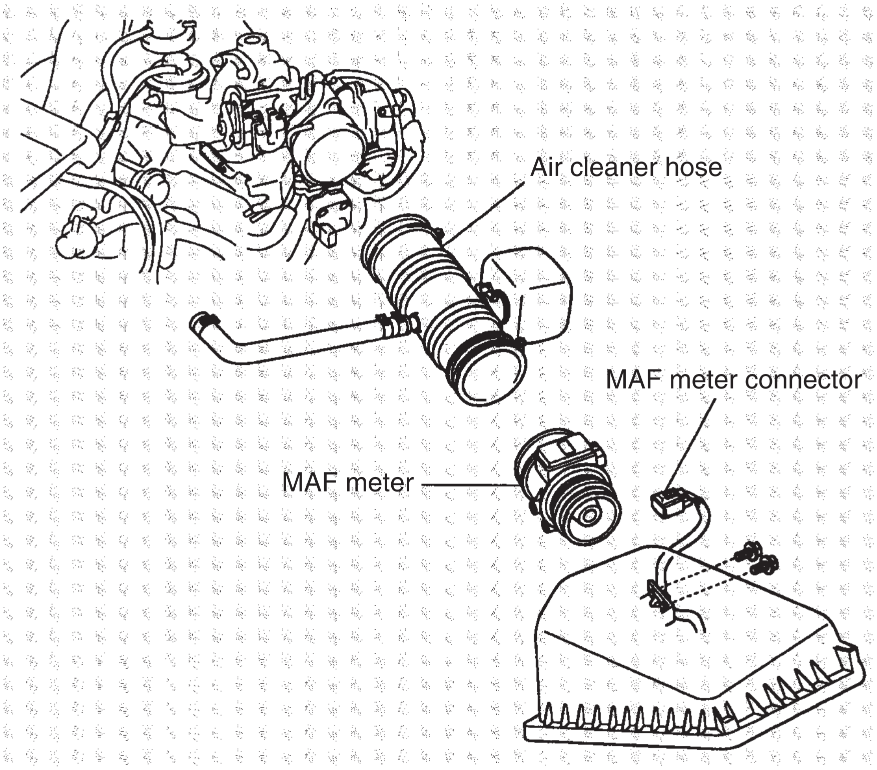


Figure 17–26 MAF sensor (meter).

INPUTS

Mass Air Flow Sensor

The MAF sensor provides the PCM with a fluctuating analog voltage signal corresponding to the amount of air passing through the air intake system (Figure 17–26).

Heated Oxygen Sensors

The Toyota system uses front and rear oxygen sensors (Figure 17–27) in the same way as the Nissan system described previously in this chapter. On V6 engines, there are two front oxygen sensors, one for each bank. The front oxygen sensors generate the signals the computer uses for closed-loop fuel mixture control, and the rear sensor is used to determine the effectiveness of the catalytic converter. Should either front sensor

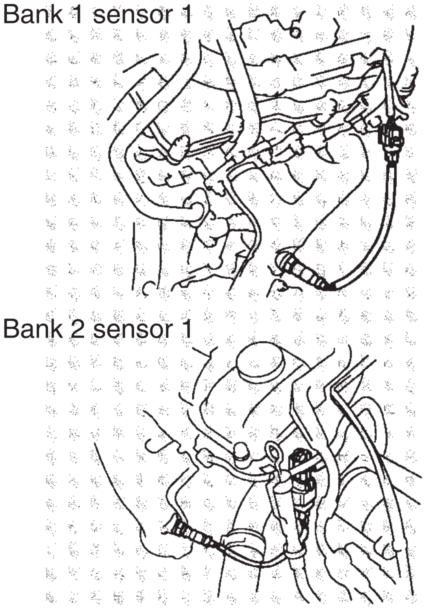


Figure 17–27 Heated oxygen sensor.

fail, the rear sensor signal is used to help maintain fuel trim. The oxygen sensors all include a heater circuit to bring them up to operating temperature as quickly as possible in order to run the engine in closed loop.

Throttle Position Sensor

The throttle position (TP) sensor (Figure 17–28) provides the computer with information about where the driver's foot has positioned the accelerator pedal. On the Toyota system, the TP sensor is adjustable using a feeler gauge between the throttle stop screw and stop lever and an ohmmeter on the terminals, as shown in the shop manual. A defective TP sensor can lead to the wrong idle speed and poor driveability at other speeds.

Engine Coolant Temperature Sensor

The ECT sensor (Figure 17–29) varies its internal resistance inversely with temperature; that is, the warmer it gets, the lower its resistance goes. It threads into the water jacket near the thermostat outlet and can be checked with an ohmmeter. At normal shop temperature, it should indicate approximately 2000 Ω. The computer uses information from the ECT sensor to calculate fuel mixture, spark advance, and ignition timing. Its information also plays a role in determining when to go into closed loop, when to engage the EGR system, and when to open the passages to the evaporative emissions charcoal canister.

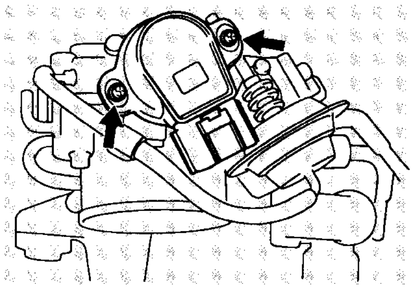


Figure 17–28 Throttle position sensor.

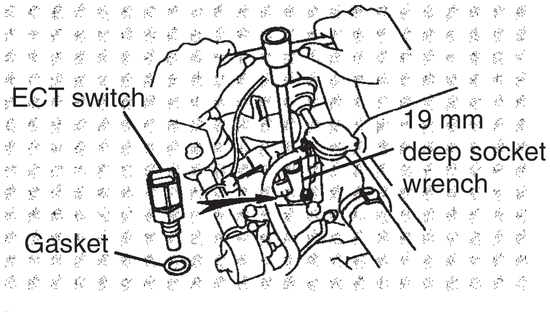


Figure 17–29 ECT sensor.

Knock Sensors

V6 engines use two knock sensors, one on each bank (Figure 17–30); in-line engines use one. The knock sensor, as on other systems, is a piezoelectric unit that, when vibrated at a frequency characteristic of knock, sends a signal to the computer, which then retards spark advance until the knock disappears. Spark advance is then re-advanced until the knock just reappears. Like most knock sensors, its function can be checked by tapping on the engine block adjacent to the knock sensor with a tool while observing the spark advance (warm engine, closed-loop conditions). Knock sensors are relatively delicate and should never be dropped. If dropped to a hard surface, they will frequently sustain damage.

EGR Temperature Sensor

To determine whether its EGR system actuation commands are effective, the computer monitors information from the EGR temperature sensor (Figure 17–31). When the EGR passage opens, hot exhaust gas travels through the

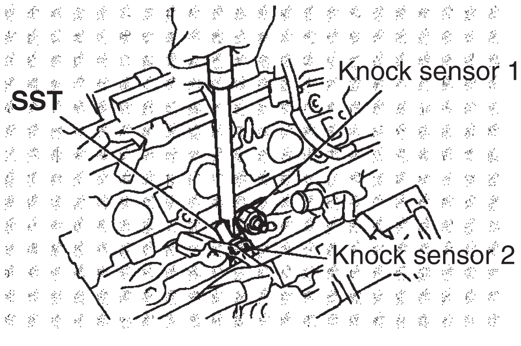


Figure 17–30 Knock sensors.

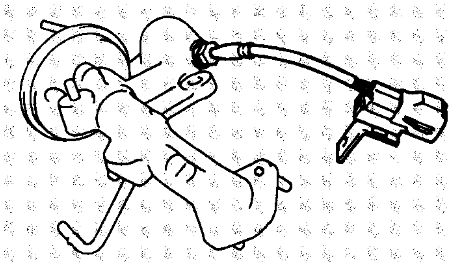


Figure 17–31 EGR temperature sensor.

channel, and the temperature sensor should reflect an increased temperature. This information does not enter into direct control of the engine, but does play an important role in the self-diagnostics of the system's emissions controls.

Camshaft Position Sensor

The latest Toyota V6 engines use a direct ignition system with one coil per cylinder rather than a distributor, and they therefore require a camshaft position (CMP) sensor (Figure 17–32). This sensor is on one of the camshaft sprockets on the accessory drive side of the engine. Its purpose is to enable the computer to determine which cylinder is approaching its power stroke firing position, information it uses both for spark firing and for fuel-injection sequencing. The CMP sensor is a coil-and-magnet inductive sensor, generating a current that alternates as the camshaft turns. Electrical resistance should range from a cold value of 835 Ω to a hot resistance of 1645 Ω.

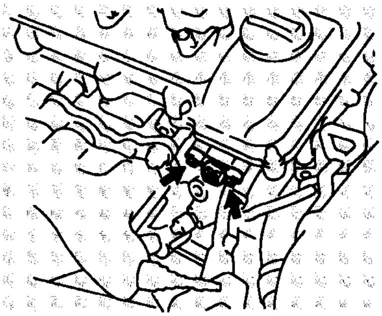


Figure 17–32 CMP sensor.

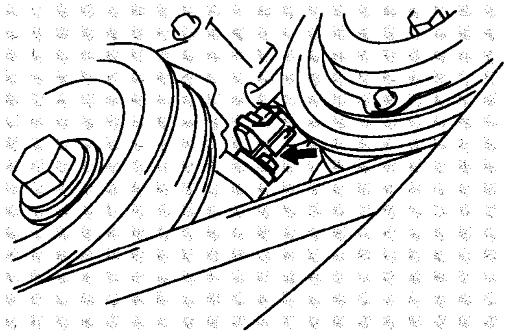


Figure 17–33 CKP sensor.

Crankshaft Position Sensor

The CKP sensor (Figure 17–33) is adjacent to the crankshaft pulley. It provides the computer with information about the position and speed of the crankshaft, information employed for fuel injection, spark timing, and idle control, as well as functions restricted to on-board diagnostics. Resistance across the magnet-and-coil CKP sensor should range from a cold value of 1630 Ω to a hot value of 3225 Ω.

OUTPUTS

Fuel Injectors

The fuel injectors (Figure 17–34) are Bosch-design units, one for each cylinder. The computer sprays them sequentially in the firing order of the

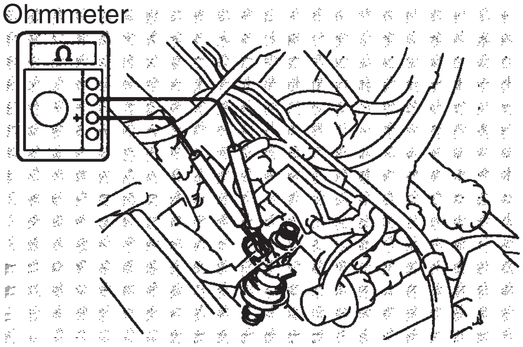


Figure 17–34 Fuel-injector resistance check.

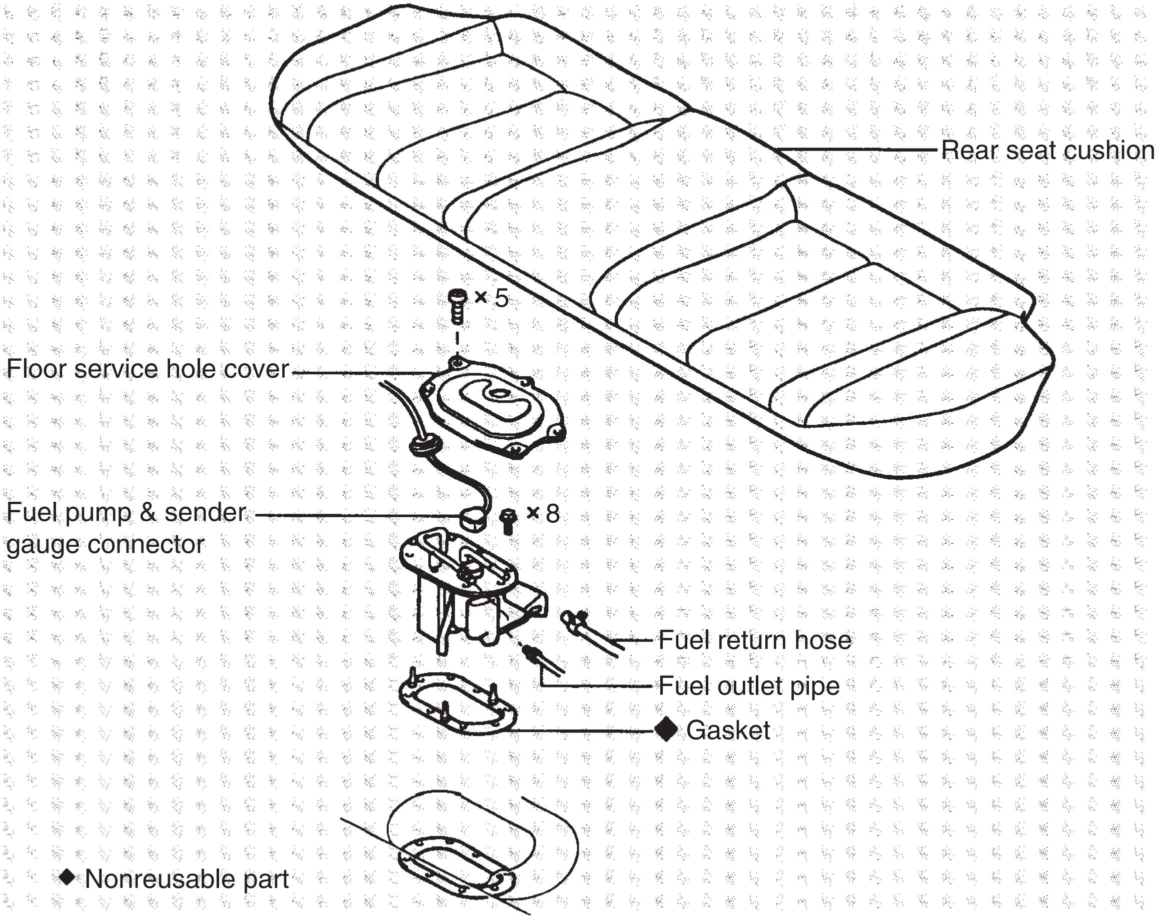


Figure 17–35 Fuel pump.

engine during the corresponding cylinder's intake stroke. At room temperature, each injector's coil should have approximately 13.8 Ω resistance. Injectors are subject to mechanical restrictions and blockages, so they should be separately inspected for flow and spray pattern if there is reason to suspect they are not working properly.

Fuel Pump Circuit

The fuel pump on many Toyota systems is under a plate beneath the rear seat (Figure 17–35). The computer energizes a main fuel-injection relay (Figure 17–36) that in turn activates

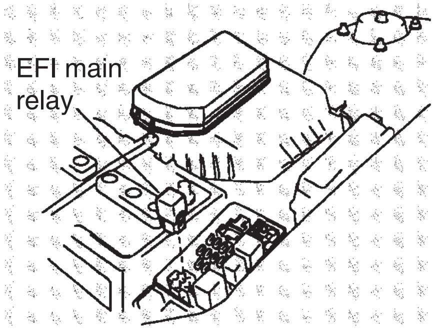


Figure 17–36 EFI (fuel pump) main relay.

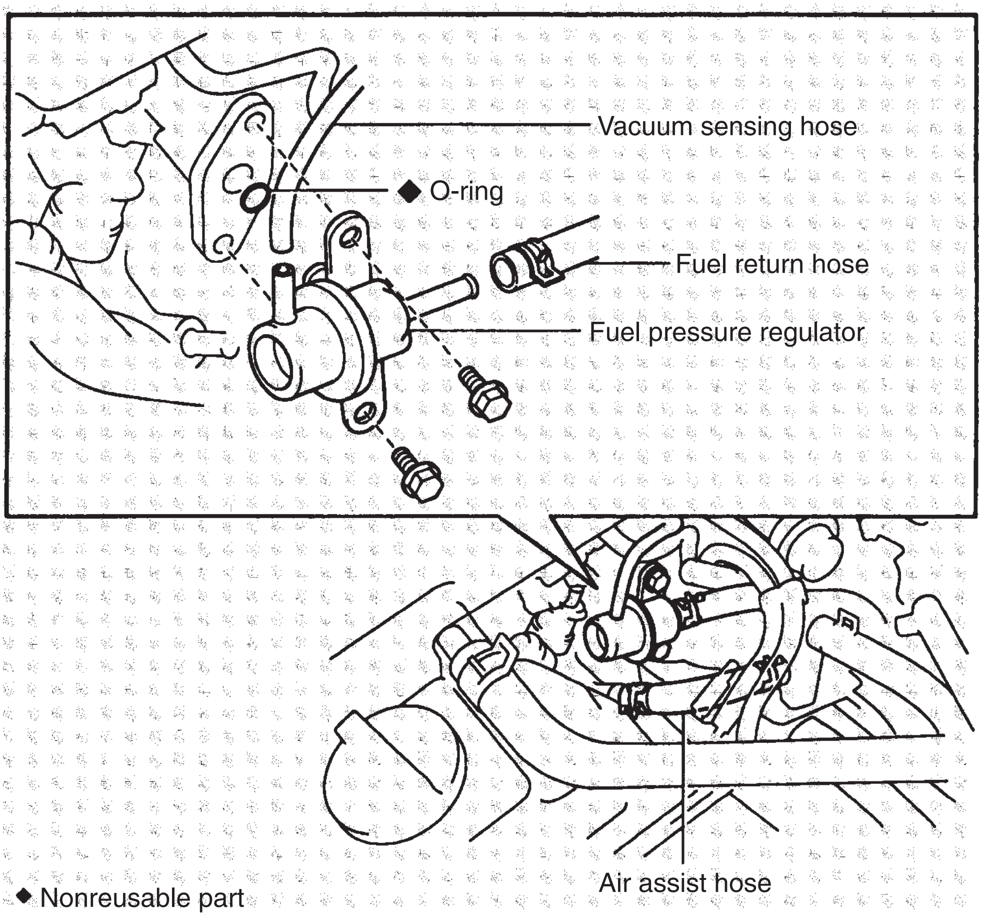


Figure 17–37 Fuel pressure regulator.

the fuel pump. As on most systems, the fuel pump comes on for approximately 1 second after the ignition key is turned on to prime and pressurize the injectors and fuel rail, then shuts off if no CMP signal is received after the priming second.

The fuel from the pump fills the fuel rail; pressure is controlled by the fuel pressure regulator (Figure 17–37). The regulator bolts into the end of the fuel rail and reduces pressure corresponding to intake manifold vacuum, sending unused fuel back to the tank. The fuel pressure regulator, of course, is not directly controlled by the computer but responds to the pressure from the fuel pump and the partial vacuum in the intake manifold.

Toyota has shifted to the returnless fuel system. This change reduces fuel tank emissions caused by the return of fuel from the engine compartment. As in other manufacturers' systems, this returned fuel contains heat absorbed when the fuel was in the engine-mounted fuel injector rail. Fuel in excess of that needed by the engine does not leave the fuel tank. A pressure regulator is located inside the tank above the submersible fuel pump. When the fuel moves outside the tank, it must go immediately to the fuel rail or it must be returned to the fuel tank through the fuel pressure regulator (Figure 17–38).

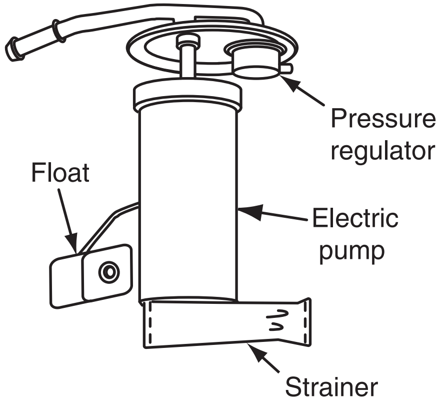


Figure 17–38 Fuel tank module.

Diagnostic & Service Tip

On the Toyota IAC valve and on others of similar design, it is almost always a better service practice to replace the gasket between the valve and the throttle body any time it is removed. Failure to do so can allow "false air" to pass around the gasket and into the intake manifold, making it more difficult or even impossible for the computer to correctly control the idle speed. This type of problem ordinarily does not set a code, so solving it takes more time than the repair is worth.

Idle Air Control System

Figure 17–39 shows the IAC valve. It bolts to the throttle body and provides a bypass channel for air to pass the throttle blade for idle speed control, depending on the ECT, electric, and other accessory loads and whether the car is in a drive gear. The IAC valve is easily removed from the throttle body and can be inspected by jumping the connections to see whether the valve opens and closes properly.

Ignition Coils

The latest V6 engines use a direct ignition system with one coil and driver transistor per pair of cylinders (a waste spark system) (Figure 17–40). Ignition coil resistances should be 0.70 to 1.10 Ω through the primary circuit and 10.8 to 17.5 KΩ through the secondary circuit, ranging from cold to hot temperatures. With individual coils of this design, the most time-efficient test for a bad coil is often to merely shift the coil from one cylinder to another to see whether the cylinder miss follows the coil. If it does not, of course, diagnosis should focus on fuel or mechanical aspects of the affected cylinder.

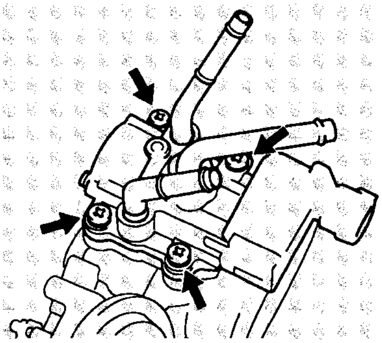


Figure 17–39 Idle air control valve.

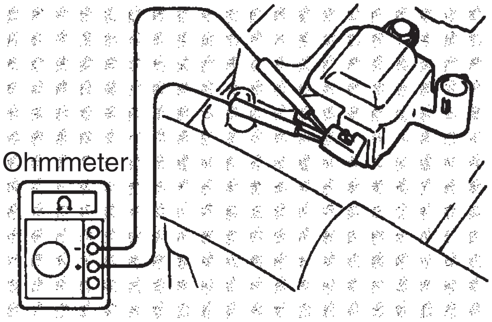


Figure 17–40 Ignition coil resistance check.

Toyota has a waste spark ignition system that looks different from most other waste spark ignition systems. Here is how it works:

This system gets its name from the exhaust cycle. As in the traditional waste spark system, one coil fires two cylinders at the same time. One cylinder is in the compression cycle while the other is in the exhaust cycle. This system uses the three principles of series circuitry. The first principle states that resistance adds together in a series circuit. This means the coil's secondary resistance, the spark plug's internal resistance, the spark plug's gap, and the secondary wire resistance all are added together. The second principle states that "current is consistent throughout all parts of a series circuit." Therefore, the current flow across both spark plug electrodes in the circuit is the same. The third principle states that voltage drops must equal the power supply. In other words, as electricity travels through each resistance it pays a price. That price is called *voltage drop*. The voltage required to power the spark plug during the compression cycle is higher than the voltage required to power the spark plug during the exhaust cycle. However, the coil's electrical potential is so high because of the increased on-time. The ignition reserve is never exceeded.

The waste spark management system has an unusual design. It is an *on-the-coil* system for one side of the engine but not for the other side. The individual coils that control two cylinders are located on one side of the engine. This side uses no secondary wires to deliver the ignition spark. The opposite side of the engine receives ignition spark through traditional secondary wires (Figure 17–41).

Resistances for this coil are:

Primary	0.7 to 0.94 Ω (cold) 0.85 to 1.10 Ω (hot)
Secondary	
Asian made	10.8 to 14.9 KΩ (cold) 13.1 to 17.5 KΩ (hot)
Diamond made	6.8 to 11 KΩ (cold) 8.6 to 13.7 KΩ (hot)

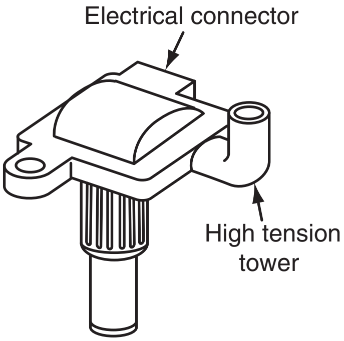


Figure 17–41 Waste spark coil.

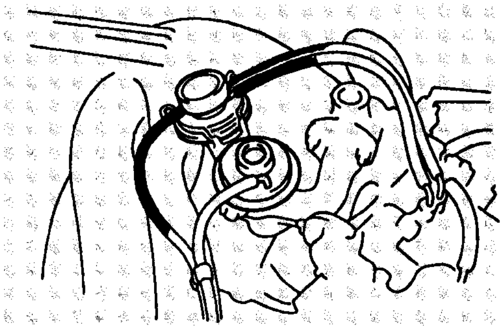


Figure 17–42 EGR vacuum modulator.

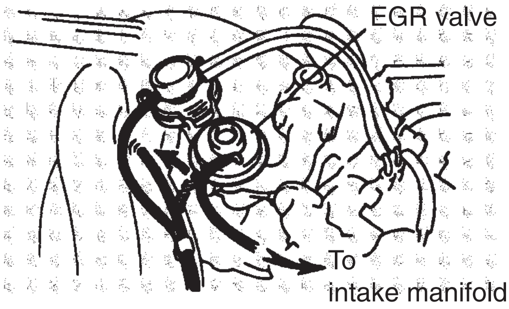


Figure 17–43 EGR valve.

EGR System

The exhaust gas recirculation system on late-model Toyotas uses a vacuum modulator (Figure 17–42) to activate the EGR valve (Figure 17–43). The EGR system should not be in operation at all below an engine coolant temperature of 131°F. The EGR vacuum modulator can be opened and cleaned/inspected for holding vacuum. With the engine warm, check that the modulator passes vacuum along to operate the EGR valve itself and that it opens when actuated. Exact connections to perform these checks can be found in the appropriate shop manual.

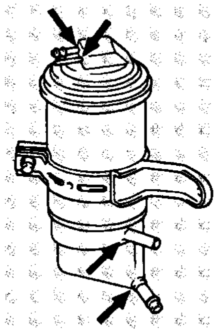


Figure 17–44 EVAP system charcoal canister.

EVAP Control System

Like most manufacturers, Toyota uses a charcoal canister (Figure 17–44) to store fuel vapors and burn them later when the engine is running. With the newer OBD II–compliant vehicles, any detected vapor leaks—including a leaking or missing fuel filler cap—can set a code and turn on the check engine light. While most manufacturers have placed the pressure sensor in the top of the fuel tank, Toyota has chosen to locate the pressure sensor at the vapor canister and associated hoses (Figure 17–45).

Variable Valve Timing with Intelligence

In 1998, Toyota introduced an engine equipped with variable valve timing (VVT). The recipient of this technology was the Supra and its normally aspirated 3.0-L, dual overhead camshaft, 24-valve, in-line 6. (The Supra's twin turbocharger-fitted version of this 3.0-L in-line 6 retains fixed valve timing for the 1998 model year, but still manages to develop 320 horsepower and 315 ft.-lbs. of torque.) The Toyota system, named Variable Valve Timing with intelligence (VVT-i), was developed in response to ever more strict emissions requirements, but horsepower and torque are increased too. The VVT-i–equipped engine develops 225 horsepower and 220 ft.-lbs. of torque at 4000 RPM.

In the VVT-i system the engine management computer looks at a variety of inputs including coolant temperature, engine speed, and engine load. The computer then controls valve overlap (the period of time during which both the intake valve and the exhaust valve are open) by advancing or retarding the intake camshaft. The VVT-i system control devices are an Oil Control Valve (OCV) and a special intake camshaft timing pulley (VVT pulley) (Figure 17–46). Changing the intake camshaft "timing" while the engine is operating allows all of the typical factors that must be juggled during camshaft design—low RPM torque, high RPM power, engine smoothness, emissions, and fuel efficiency—to be optimized. A unique feature of the Toyota VVT-i system is that camshaft timing

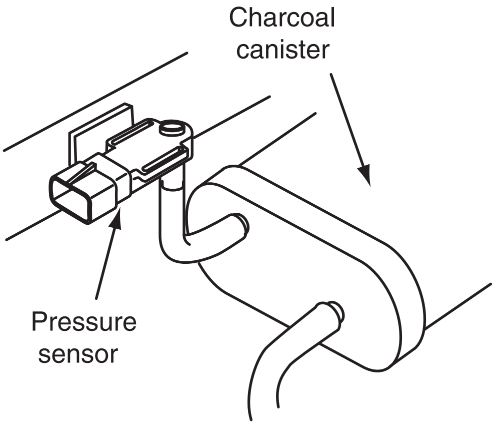


Figure 17–45 EVAP canister.

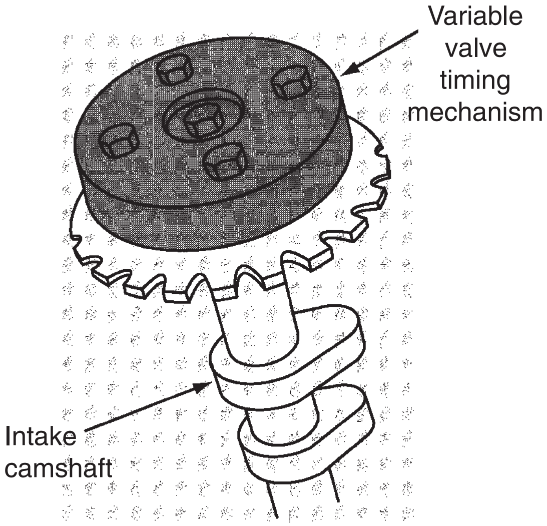


Figure 17–46 Intake camshaft and VVT unit.

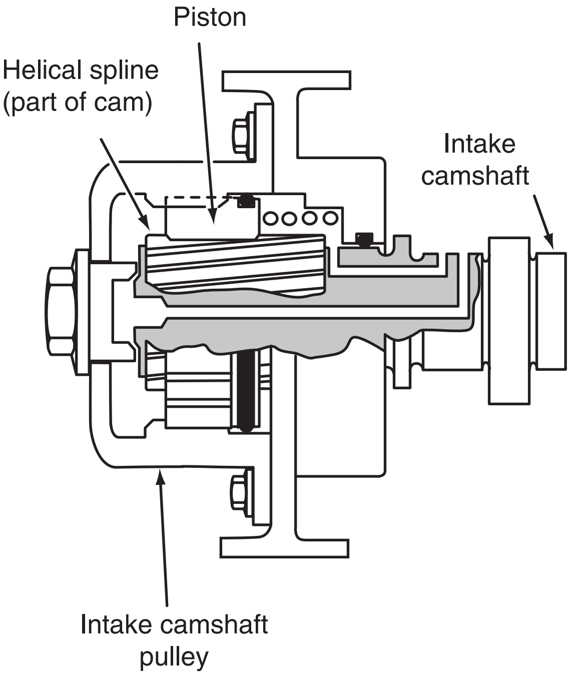


Figure 17–47 VVT-i camshaft timing pulley.

is continuously adjustable; competitive systems allow only two or three distinct camshaft "settings" that are strictly RPM dependent.

The VVT-i sprocket used in the system has a piston with helical splines cut into both its inner and outer surfaces (Figure 17–47). The inner surface meshes with a splined gear attached to the end of the intake camshaft, while the outer surface meshes with a splined cup attached to the camshaft sprocket. Pressurized engine oil is applied to one side of the piston through the OCV, causing the piston to move axially. This axial movement changes the drive sprocket position relative to the camshaft. The engine management computer modulates the OCV to control camshaft timing, monitoring signals from the camshaft and crankshaft position sensors to determine actual camshaft position.

Two-Way Exhaust Control

Toyota recently introduced a method to control exhaust system backpressure. Exhaust gasses are routed through the entire pathway of the muffler when the engine is at idle. This quiets exhaust noise. When the engine operates at higher speeds, the muffler provides a shorter route through a spring-loaded door, which reduces system pressure and improves engine performance. This route, shown in Figure 17–48, is both shorter and noisier.

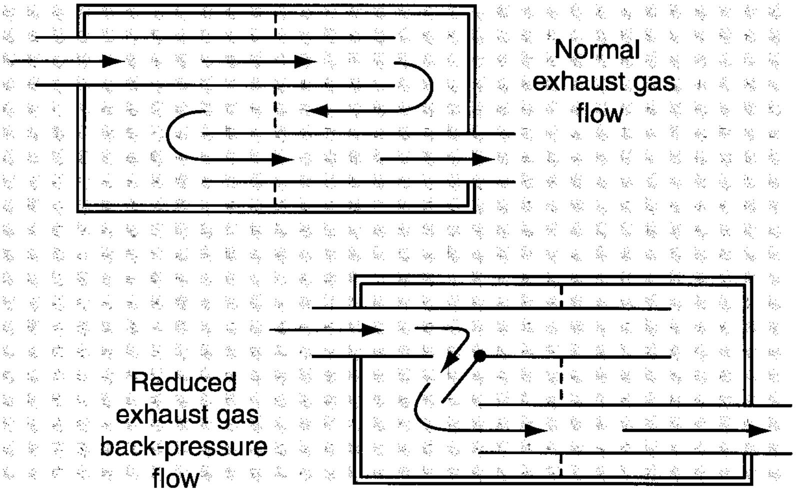


Figure 17–48 Typical two-way exhaust control muffler.

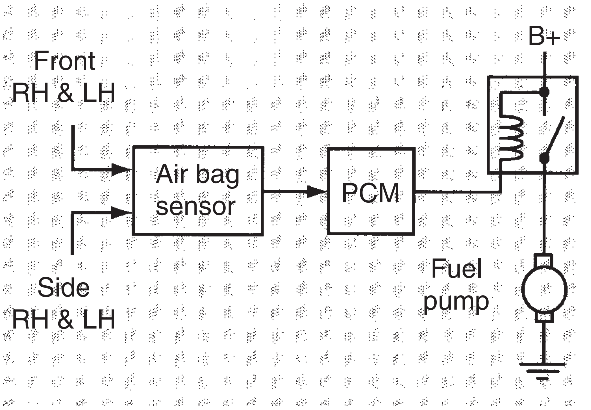


Figure 17–49 In case of an air bag deployment, the electric fuel pump is shut off.

Supplemental Restraint System (SRS)

The 2000 model-year Toyota integrates air bag deployment into the fuel pump drive program. If either the front or side air bag is deployed, the electronic control module stops grounding the fuel pump relay. Figure 17–49 shows that this opens the fuel pump feed circuit and stops the fuel pump.

Compressed Natural Gas (CNG)

The 2000 Toyota Camry introduced a natural gas version 5S-FNE-CNG engine. The CNG engine has a new fuel rail design, shown in Figure 17–50, that has an electric fuel shutoff valve at one end, a fuel temperature sender midway down the rail, and a fuel pressure sensor and discharge port at the other end.

The additional hoses, regulators, solenoids, and gas shutoff valve are not evident on the Camry until the vehicle is elevated. A large-diameter pressurized fuel tank is located at the rear of the vehicle. The fuel tank occupies most of the trunk space.

Active Control Engine Mount (ACEM)

The Avalon V6 engine has an active oil-filled engine mount. The mount contains a chamber divided by a rubber diaphragm. The chamber, shown in Figure 17–51, has computer-controlled engine vacuum on one side of the diaphragm; the other side of the diaphragm contains damping oil that is used to lessen engine vibration at idle.

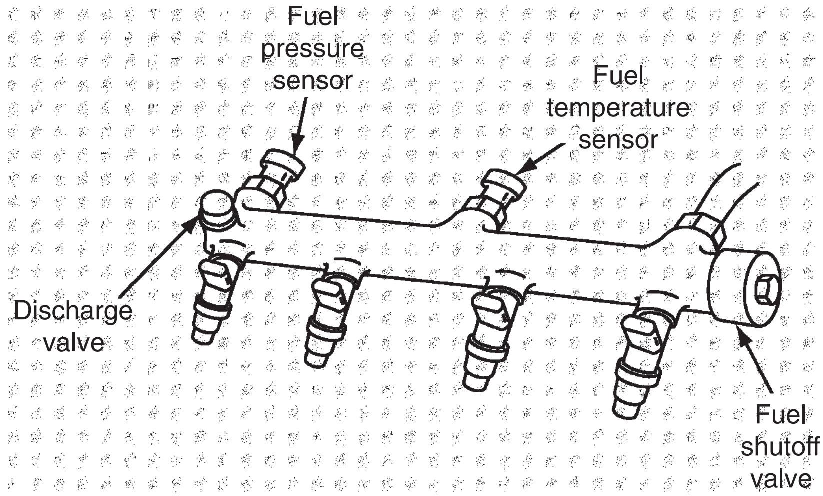


Figure 17–50 The fuel rail used on the CNG vehicle contains a pressure sensor, temperature sensor, shutoff valve, and a gauge test point.

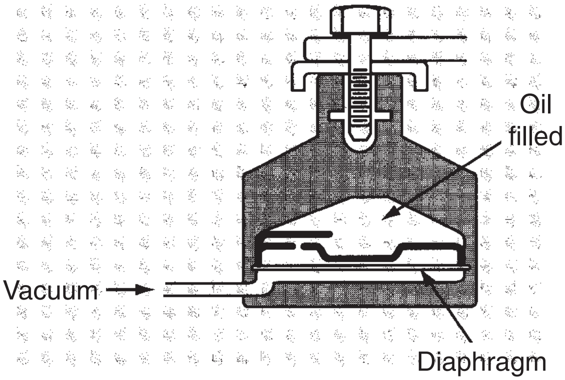


Figure 17–51 A cutaway active control engine mount (ACEM).

At idle or at engine speeds of less than 900 RPM, the computer sends pulses to an electrically operated vacuum control valve. These signals are synchronized to engine RPM. The vacuum travels to the lower side of the rubber diaphragm inside the engine mount. The diaphragm vibrates, transferring that vibration through the damping oil into the rubber mount. The mount cancels out unwanted engine vibration. Figure 17–52 shows the components of the ACEM.

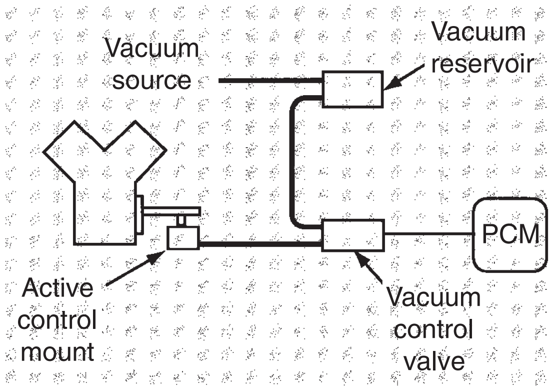


Figure 17–52 Electrical circuit of ACEM.

✔ SYSTEM DIAGNOSIS AND SERVICE

OBD II Diagnostics

The first manufacturer on the street with a fully OBD II–compliant engine control system was Toyota, as early as 1994. This was a considerable engineering accomplishment, especially in light of the fact that some other import manufacturers had stated early on in discussions about the OBD II requirements that they would have to use add-on modules to meet the standards.

Toyota's OBD II strategies closely resemble those of U.S. domestic vehicle manufacturers. Like other vehicle manufacturers, Toyota uses some proprietary DTCs as well as generic OBD II DTCs. With 1996 and newer Toyotas, generic OBD II scan tools may be used for diagnosis using the standardized data link connector in the lower left area of the instrument panel (Figure 17–53). Most component or signal failures that can affect the vehicle's emissions, fuel economy, or engine performance will be reflected in the information available on the scan tool.

Remember that the setting of a DTC represents a failure in any portion of the circuit that the DTC refers to and only helps to enable the technician to narrow down the fault area. Although performing a visual check and other pinpoint tests of the component is a reasonable first step (Figure 17–54),

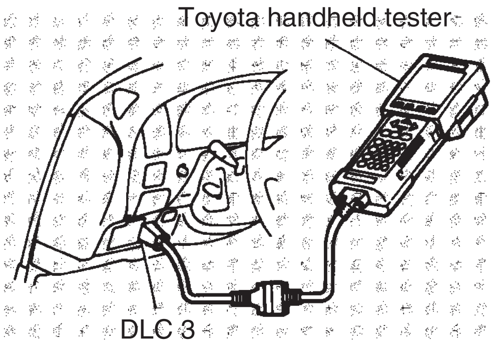


Figure 17–53 OBD II diagnosis with scan tool.

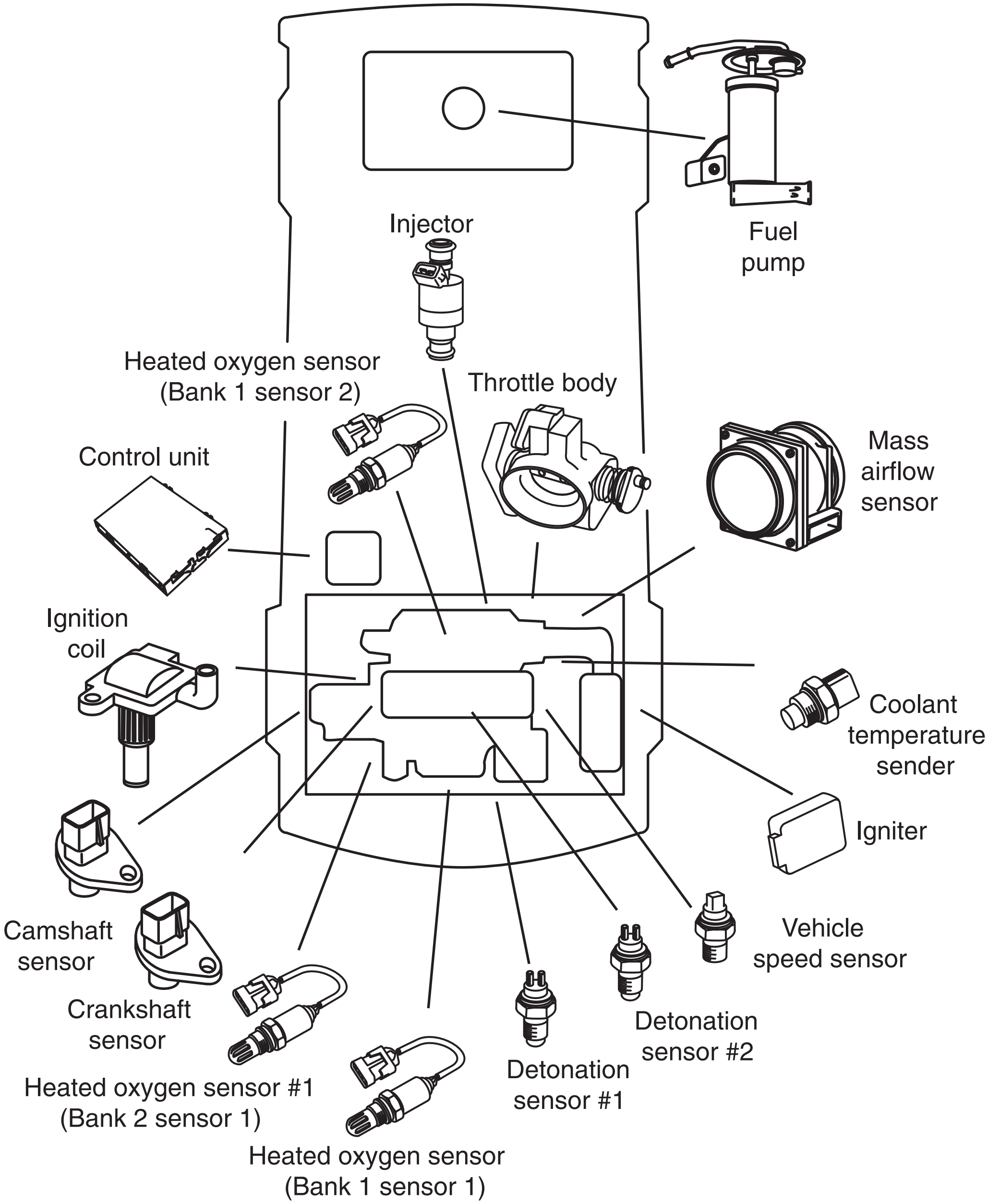


Figure 17–54 Component locations.

the problem may actually be in the circuitry's wiring and connectors or even in the computer.

HONDA: PROGRAMMED FUEL INJECTION (PGM-FI)

The Honda PGM-FI system is a computerized control system that provides optimum control of the engine's fuel, spark, and emissions control systems and also provides control of the automatic transaxle. It was introduced in 1985 and has been updated according to OBD I (1988) and OBD II (1996) standards. Since the mid-1990s, it has allowed for bidirectional communication between the PCM and a scan tool.

INPUTS

Manifold Absolute Pressure Sensor

On Honda vehicles, an analog manifold absolute pressure (MAP) sensor is used to measure engine load. Since the early 1990s, the MAP sensor is also used to update the barometric pressure values in the PCM's memory whenever the engine is started and during wide-open throttle operation. The MAP sensor receives a reference voltage from the PCM and returns an analog voltage that equates to manifold pressure. As intake manifold pressure is decreased (as vacuum is applied), the MAP sensor voltage also is decreased in a manner similar to the MAP sensors found on GM vehicles. The PCM uses the resulting signal, along with other sensor signals and programmed information, to calculate how much air is entering the engine. This calculation is known as the *speed density formula*. (See Chapter 3 for additional information on the speed density formula.) Depending on the year and model, Honda MAP sensors may be found in a variety of locations. Newer ones are located attached to the intake manifold to eliminate the need of an attaching vacuum hose.

Barometric Pressure (Baro) Sensor

Honda initially used a full-time barometric pressure (baro) sensor, known prior to OBD II standardization as the *pressure absolute (PA) sensor*. This sensor is an analog sensor, returning an analog DC voltage to the PCM that indicates sensed barometric pressure. Originally designed as a separate sensor, the baro sensor was relocated within the PCM in 1988 (similar to some Chrysler vehicles of the mid-1980s). Then, in the early 1990s, the baro sensor disappeared from Honda vehicles and the PCM was reprogrammed to obtain barometric pressure values from the MAP sensor, as is done in most other modern vehicles.

Heated Oxygen Sensors

OBD II applications have a minimum of two heated oxygen sensors. A primary HO_2S is mounted ahead of the catalytic converter to help the PCM control the air/fuel mixture while in closed loop. A secondary HO_2S mounted after the catalytic converter allows the PCM to monitor converter efficiency.

Linear Air/Fuel Sensor

Hondas that are certified as low emission vehicles (LEV) or ultra-low emission vehicles (ULEV), as well as those that are equipped with a continuously variable transmission (CVT), use a primary oxygen sensor that is able to respond to a wider range of air/fuel ratios than are those on other vehicles. Known as a **Linear Air/Fuel (LAF) sensor,** this sensor is used by the PCM to accurately measure air/fuel ratios from 12:1 to 22:1. (Standard narrow-band oxygen sensors measure air/fuel ratios ranging from about 14.3:1 to about 15.1:1 while operating in a range between 100 mV and 900 mV.) The use of this sensor allows Honda to program its PCMs to operate at a lean air/fuel ratio during cruise to increase fuel economy. During certain light load conditions, and when the temperature of combustion is such that little potential for NO_x creation exists, the PCM will drive the air/fuel mixture lean to a range between 18:1 and 22:1 while still retaining closed-loop operation. Whereas most spark-ignition engines can potentially begin to experience a lean misfire at around 17:1, Honda engineers have designed the combustion chamber in such a way that the immediate area surrounding the tip of the spark plug tends to get a richer air/fuel mix than the overall air/fuel mix delivered to the cylinder. As a result, these engines can be run quite lean without experiencing any lean misfire symptoms. Originally incorporated on 1992 to 1995 Civic VX, 1996 to 1998 Civic HX, and 1998 Accords, the use of the LAF sensor has continued to spread across Honda LEV and ULEV applications.

The LAF sensor consists of two zirconium dioxide oxygen sensors in one assembly (Figure 17–55). Sensor 1 is on the outside of the assembly, in the exhaust stream. Sensor 2 is located inside of the concave shape of sensor 1. The area between the two sensors, the *diffusion chamber*, is sealed. The outer surface area of sensor 1 samples exhaust gas. The inner surface area of sensor 2 samples ambient oxygen. Both the inner surface area of sensor 1 and the outer surface area of sensor 2 sample oxygen content within the diffusion chamber.

Five wires originate at the sensor assembly, two of which serve as the heater positive and heater ground wires. Of the three remaining wires, the wire labeled “reference voltage” is connected to both the inside surface area of sensor 1 and the outside surface area of sensor 2. The voltage signal on this wire should be 2.7 V when tested with a voltmeter connected between the wire and a clean, unpainted engine ground. A second wire, the *cell voltage input,* is connected to the outside surface area of sensor 1 and will input a value to the PCM representing the voltage difference between the exhaust side and the diffusion chamber side of sensor 1. However, unlike traditional oxygen sensors on which this voltage

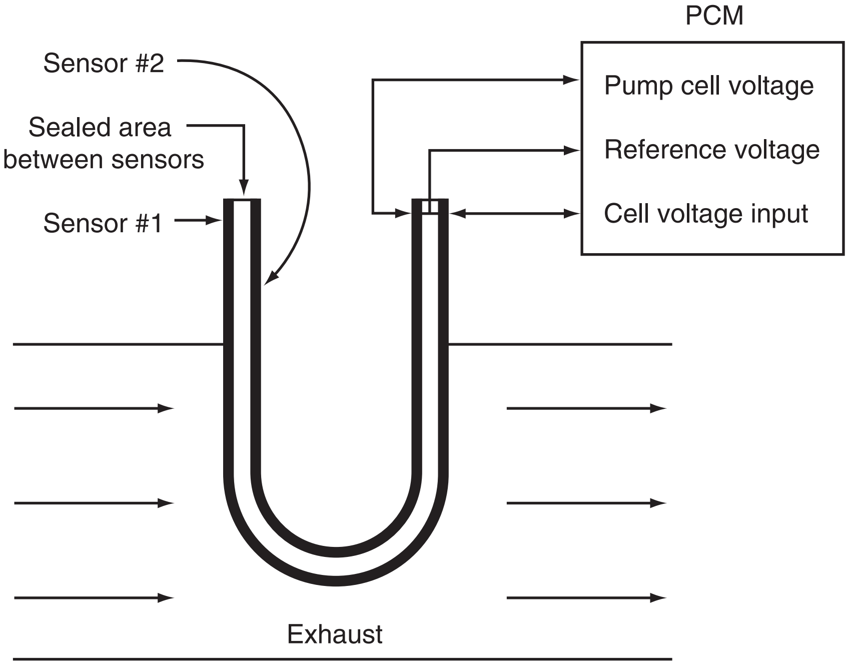


Figure 17–55 LAF sensor circuit.

would cross count to both sides of 450 mV, this signal will actually be maintained at 450 mV during closed-loop operation. This is accomplished through the third wire, the *pump cell voltage* circuit. The PCM uses this circuit to effectively vary the amount of oxygen in the diffusion chamber. When the PCM places a positive voltage on this wire, the amount of oxygen within the diffusion chamber is increased. When the PCM places a negative voltage on this wire, the amount of oxygen within the diffusion chamber is decreased. The PCM can vary the voltage on the pump cell voltage circuit from –1000 mV to +1000 mV in an attempt to keep the cell voltage input signal right at 450 mV.

Phrased differently, if the engine's air/fuel ratio begins to go rich, causing the cell voltage input signal to rise above 450 mV, the PCM issues a negative voltage on the pump cell voltage circuit, thus decreasing the oxygen on the diffusion chamber side of sensor 1 to match the decrease in oxygen in the exhaust gas. This allows the rising voltage on the cell voltage input circuit to settle back to 450 mV. Conversely, if the engine's air/fuel ratio begins to go lean, causing the cell voltage input signal to fall below 450 mV, the PCM issues a positive voltage on the pump cell voltage circuit, thus increasing the oxygen on the diffusion chamber side of sensor 1 to match the increase in oxygen in the exhaust gas. This allows the falling voltage on the cell voltage input circuit to increase back to 450 mV.

Ultimately, the PCM calculates the air/fuel ratio from the amount of positive or negative voltage that it has to place on the pump cell voltage circuit to maintain a 450-mV signal on the cell voltage input circuit.

Throttle Position Sensor

The throttle position (TP) sensor is a rotary potentiometer that informs the PCM of driver demand. It is found at the throttle body on one end of the throttle shaft and is similar to those found on most other makes. Prior to OBD II standardization, this sensor was referred to as the *throttle angle (TA) sensor.*

Engine Coolant Temperature Sensor

The engine coolant temperature (ECT) sensor is a negative temperature coefficient (NTC) thermistor, changing its resistance in response to changes in engine temperature. As the engine's coolant warms, the ECT sensor's resistance decreases, resulting in a decrease of the voltage-drop signal that is measured across the sensor by the PCM. Prior to OBD II standardization, this sensor was referred to as the *temperature water (TW) sensor*.

Intake Air Temperature Sensor

The intake air temperature (IAT) sensor is an NTC thermistor that changes its resistance in response to changes in the temperature of the air entering the intake manifold. As the temperature of the intake air increases, the IAT sensor's resistance decreases, resulting in a decrease of the voltage-drop signal measured across the sensor by the PCM, like the ECT sensor. Prior to OBD II standardization, this sensor was referred to as the *temperature air (TA) sensor*.

Knock Sensor

The knock sensor is a piezoelectric crystal used to sense spark knock in the engine, similar to most other makes. The PCM reacts to input from the knock sensor by adjusting ignition timing until the knock disappears.

Exhaust Gas Recirculation Valve-Lift Sensor

The EGR valve-lift sensor is a linear potentiometer that is mounted on top of the EGR valve to measure the position of the EGR valve. This sensor is equivalent to the EGR valve position sensor found on other makes, such as Ford products with the EEC III and EEC IV systems.

Ignition Pickups: Early Distributor Applications

Crank Angle Sensor. The crank angle sensor consists of two magnetic pickups contained

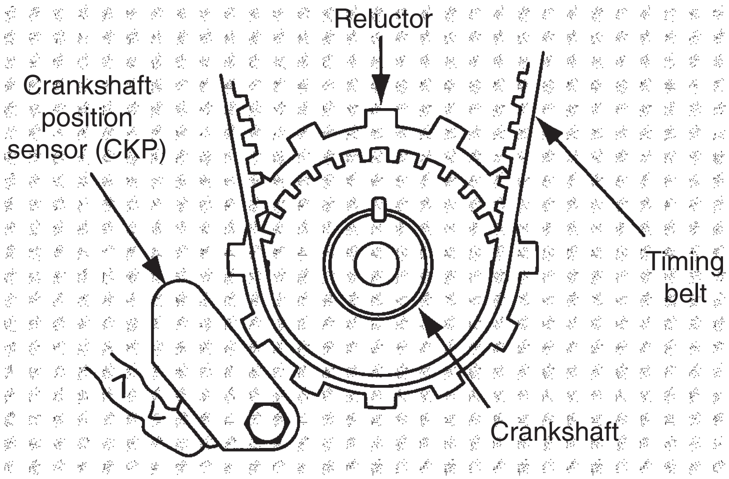


Figure 17–56 Reluctor gear on crankshaft and CKP sensor.

within the ignition system's distributor housing. Each one monitors a separate reluctor and generates AC voltage pulses. One provides the basic tach reference signal for all cylinders; the other identifies the position of cylinder 1.

Ignition Pickups: Newer Distributor Applications

Crankshaft Position Sensor and Top Dead Center (TDC) Sensor. The CKP sensor and the top dead center (TDC) sensor are both permanent magnet sensors that generate AC voltage pulses off monitored teeth on the crankshaft pulley. The CKP sensor provides the basic tach reference signal and is also used to detect when misfire is present. The TDC sensor is used to identify which piston pair is approaching TDC. The engine will not start if either sensor has failed.

Cylinder Position Sensor. The cylinder position (CYP) sensor is a permanent magnet pickup mounted within the ignition system distributor; it is equivalent to the CMP sensor found on other vehicles. It is used for fuel injector sequencing, producing one AC voltage pulse for each distributor/camshaft rotation that identifies the position of cylinder 1. If the CYP sensor were to fail, the PCM would guess at the injector sequence and the engine would continue to run.

Ignition Pickups: Coil-at-Plug Applications

A CKP sensor is used to monitor a 12-tooth reluctor located behind the timing belt drive gear at the crankshaft (Figure 17–56). In addition, two CMP sensors, known as TDC1 and TDC2, are used; they are located at the back cover of the cam gear housing (Figure 17–57).

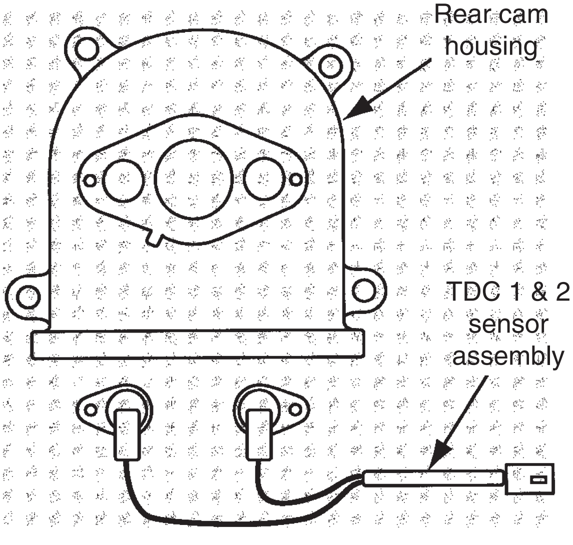


Figure 17–57 Cam housing back cover with TDC1 and TDC2 sensors.

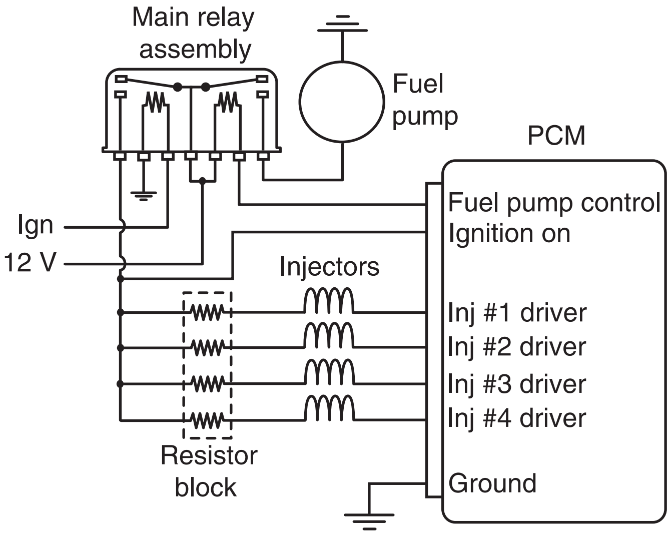


Figure 17–58 Honda main relay circuit.

OUTPUTS

Main Relay

The main relay assembly contains two relays. One relay, when energized by the ignition switch, provides power to the PCM and the fuel injectors (Figure 17–58). Beginning in 1988, it also was used to provide power to the IAC solenoid (not shown). The other is the fuel pump relay, which is under the control of the PCM.

Fuel Injectors

The Honda fuel injectors are low-resistance injectors, typically 1.5 to 3.0 Ω. When the ignition switch is turned to the run position, the main relay provides power to the fuel injectors through external resistors, one per injector (Figure 17–58). The resistor assembly is typically mounted in front of the left front shock tower.

Fuel Pump Circuit

The PCM energizes the fuel pump relay portion of the main relay assembly to run the fuel pump whenever the PCM is receiving a tach reference signal from the ignition system (Figure 17–58). The only exception to this, as with most other makes, is that the PCM energizes the fuel pump relay for 2 seconds when the PCM is initially powered up, whether or not a tach reference signal is present. This is used to top off the residual fuel rail pressure to provide an easy engine start.

Fuel-Injection Air Control Valve System

A fuel-injection air (FIA) control valve system is used on late-model Honda Accord 3.0-L and Odyssey applications. The FIA control valve allows filtered air from the air cleaner to be directed into the path of the fuel injectors' spray patterns to increase fuel atomization (Figure 17–59). The FIA valve is opened by a ported vacuum signal to improve atomization just off idle.

Idle Air Control System

By 1988, Honda PGM-FI applications incorporated an IAC valve. Known prior to OBD II standardization as the Electronic Air Control

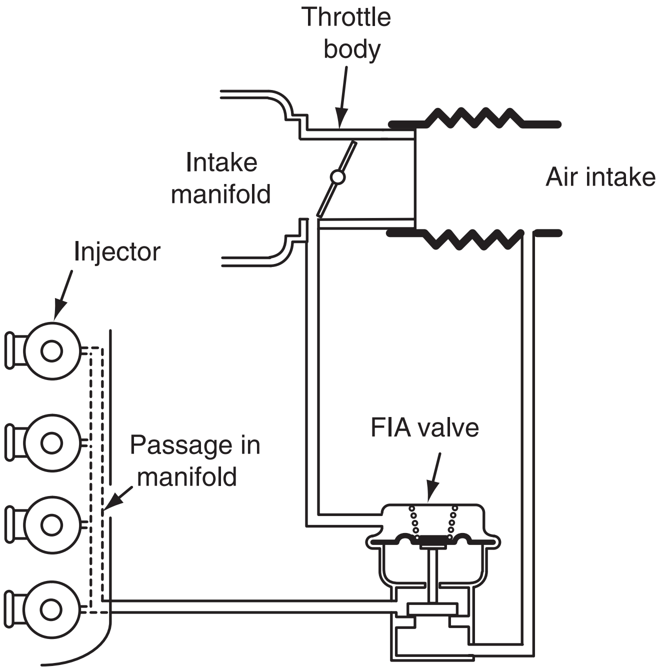


Figure 17–59 FIA control valve system.

Valve (EACV), the IAC valve is a normally closed, solenoid-operated valve that is controlled by the PCM on a duty cycle. The PCM increases the duty cycle on-time of the IAC valve to increase the flow of bypass air around the throttle plate(s).

Some early applications also used a mechanical fast idle valve to provide additional bypass air following a cold engine start. This valve was controlled through a wax pellet immersed in a coolant passage. When the engine was cold, the valve was opened to provide additional bypass air. As the engine warmed, the wax pellet expanded, closing the valve.

Ignition Coils

Honda applications used a single ignition coil and a distributor for many years. Many of these applications located the ignition coil within the distributor assembly. As Honda began to change over to EI ignition systems with multiple coils, a few early Honda Passports used a General Motors–style waste spark ignition system. Modern Honda vehicles, including 3.0-L engines in the Accord, 3.2-L engines in the Acura, and 3.5-L engines in the Acura, Odyssey, and Pilot, use a coil-at-plug design, similar to the coil-on-plug (COP) designs found on many other modern vehicles. In this design, each cylinder has its own ignition coil placed directly over the spark plug, eliminating the secondary plug wires (Figure 17–60). The ignition coils in Honda's coil-at-plug system cannot be tested in the traditional method using an ohmmeter because each ignition coil contains an electronic integrated circuit (IC) chip (Figure 17–61). The secondary winding also contains a diode. If the coil has proper power and ground and the PCM's trigger signal is present but the coil does not produce spark, the coil is at fault.

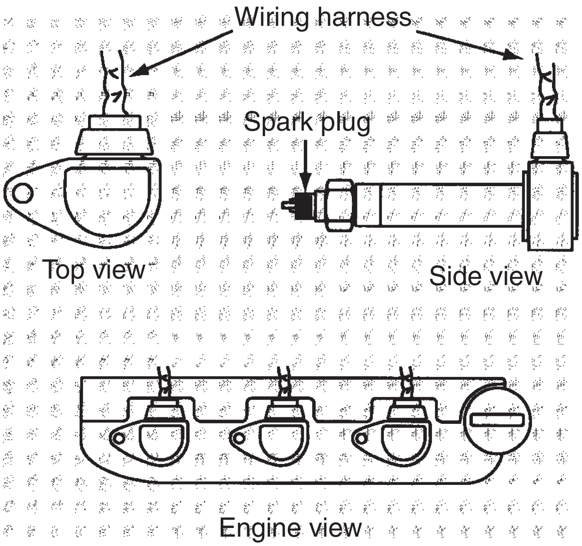


Figure 17–60 Top, side, and engine views of ignition coil used in at-plug system.

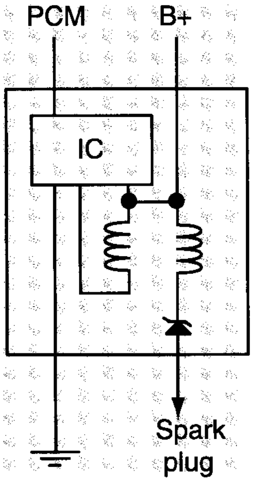


Figure 17–61 Internal schematic of ignition coil used in at-plug system.

EGR System

Honda vehicles with an EGR valve use a closed-loop EGR design. A constant vacuum control (CVC) valve receives manifold vacuum and applies a vacuum signal of 6^2 Hg to 10^2 Hg to the EGR valve—more than enough vacuum to hold the EGR wide open. The PCM then controls an EGR control solenoid that is used to vent some of the applied vacuum to atmosphere. Ultimately, the PCM controls EGR flow rates while monitoring the EGR valve-lift sensor (discussed in the "Inputs" section of this chapter).

EVAP Control System

Honda's evaporative control system allows the PCM to monitor fuel tank pressure with a pressure sensor (Figure 17–62). When fuel tank pressure exceeds a predetermined value, a two-way valve opens to allow the fuel tank to vent to atmosphere by way of the charcoal canister. The PCM also controls canister purging through a purge solenoid.

In addition, Honda uses an ORVR system. During normal vehicle operation, when the fuel cap is installed, pressure in the filler neck area is equal to the pressure within the main body of the fuel tank. However, once the fuel cap is removed, atmospheric pressure is applied to the area in the neck of the gas tank, monitored by an ORVR signal tube that controls a normally closed ORVR vent shut valve (Figure 17–62). Meanwhile, pressure within the main body of the fuel tank rises due to the fuel that is entering the tank. The ORVR vent shut valve monitors this pressure as well. The pressure differential created opens the ORVR vent shut valve, allowing vapors to be routed to the charcoal canister during refueling.

Electronic Load Detection (ELD)

Alternator output on Hondas is controlled by the PCM. The PCM reduces field current, which, in turn, reduces alternator output. Output current is based on battery charge and electrical system loads. When the battery is low, or when high electrical demands are made by various systems in the car, the PCM signals the alternator to increase output; when the battery is charged up

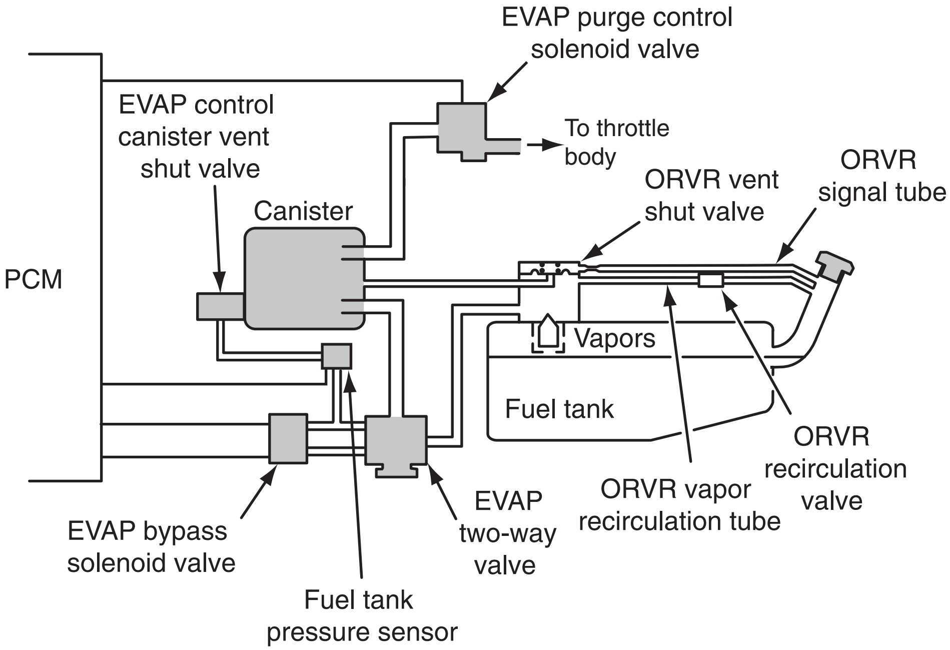

EVAP purge control solenoid valve
EVAP control canister vent shut valve
To throttle body
ORVR vent shut valve
ORVR signal tube
Canister
PCM
Vapors
Fuel tank
ORVR recirculation valve
ORVR vapor recirculation tube
EVAP two-way valve
EVAP bypass solenoid valve
Fuel tank pressure sensor

Figure 17–62 On-board refueling vapor recovery (ORVR) and evaporative system.

and there are few electrical system demands, the PCM reduces alternator output. Reduced alternator load results in better fuel economy. The PCM monitors alternator output through a Field Regulating (FR) signal that is returned to the PCM from the alternator.

Electronic Throttle Control

The Honda Passport electronic throttle control system is similar to those used by several other manufacturers. This system uses a three-channel accelerator pedal position (APP) sensor to initiate a different resistance signal for each channel. The electronic throttle control system also uses a throttle position (TP) feedback sensor. When the PCM receives the APP signal, it issues a command signal to the electric motor attached to the throttle blade. For more details on how this system works, see Chapter 12.

HONDA'S VTEC SYSTEMS

Honda has used some form of their VTEC engine technology on all of their engines since 1992. By their original definitions, Honda applications used three different systems that allow the PCM to electronically control various combinations of VVT, lift, and duration. Known initially as the "Variable Valve Timing and Lift, Electronic Control" (VTEC) systems, the three versions of this system were initially referred to as VTEC, VTEC-E, and i-VTEC.

The Original VTEC Systems

VTEC. The original VTEC system uses two intake valves per cylinder, controlled by three rocker arms (Figure 17–63). At low RPM, the rocker arms operate independently. The primary rocker arm is used to open the primary intake valve; it is controlled by a low lift, short duration lobe of the intake

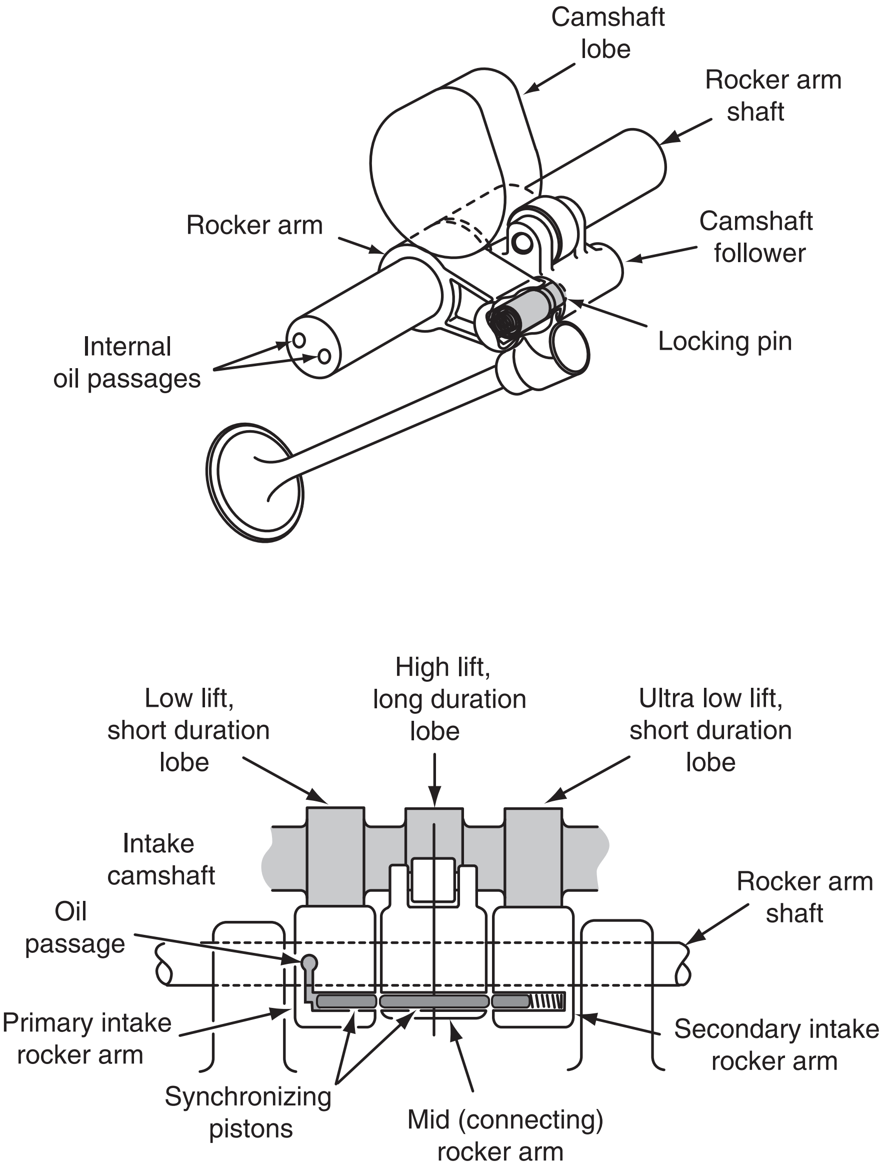

Camshaft lobe
Rocker arm shaft
Rocker arm
Camshaft follower
Locking pin
Internal oil passages
High lift, long duration lobe
Low lift, short duration lobe
Ultra low lift, short duration lobe
Intake camshaft
Rocker arm shaft
Oil passage
Primary intake rocker arm
Secondary intake rocker arm
Synchronizing pistons
Mid (connecting) rocker arm

Figure 17–63 VTEC system rocker arms operating independently.

camshaft. The secondary rocker arm is controlled by an ultra-low lift, short duration lobe that opens the secondary intake valve just enough to prevent fuel accumulation in the area of the intake port but provides little air flow. A mid (connecting) rocker arm is located between the primary and secondary rocker arms and is controlled by a high-lift, long-duration lobe. However, at low RPM, the mid rocker arm does not mechanically control any valve, but simply operates against the tension of a "lost motion" spring assembly. The primary and mid rocker arms each contain a synchronizing piston, but at low engine speeds this piston is fully contained within the respective rocker arm due to a return spring and stopper pin assembly located in the secondary piston.

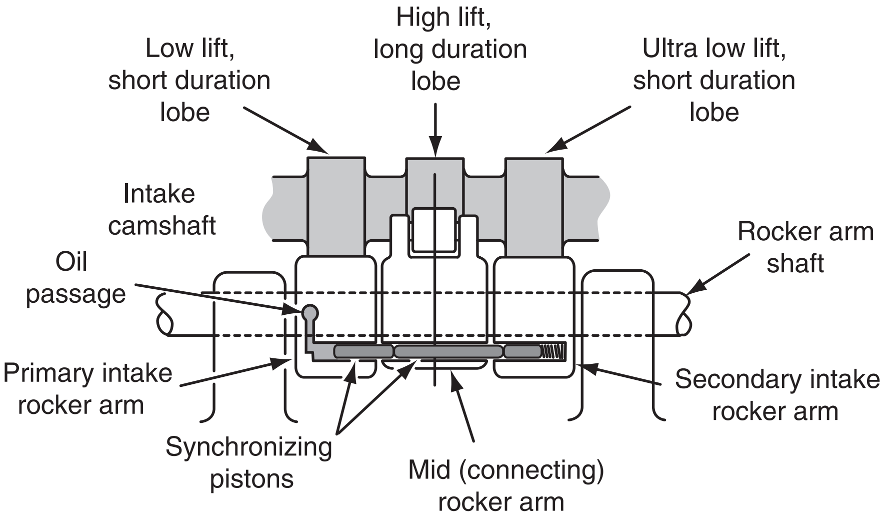


Figure 17–64 VTEC system rocker arms mechanically linked together.

At high engine RPM, the PCM energizes a solenoid that moves a spool valve. The spool valve then directs oil pressure into an oil passage within the primary rocker arm. This oil pressure then moves both synchronizing pistons toward the spring-loaded stopper pin in the secondary rocker arm, thus locking all three rockers together mechanically (Figure 17–64). This causes both the primary and secondary intake valves to be controlled according to the mid rocker arm's high-lift, long-duration cam lobe. Once the engine speed slows down again, the PCM de-energizes the solenoid, allowing the applied oil pressure to be vented from the primary rocker arm. This allows the return spring to move both synchronizing pistons back into their respective rocker arms, again allowing independent movement of each rocker arm. Figure 17–65 shows the three rocker

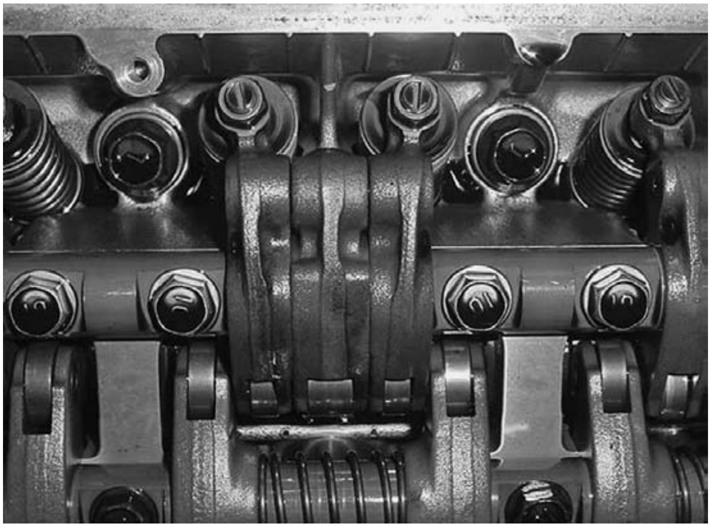


Figure 17–65 The three rocker arms of a VTEC engine. (Photo courtesy of William K. Bencini.)

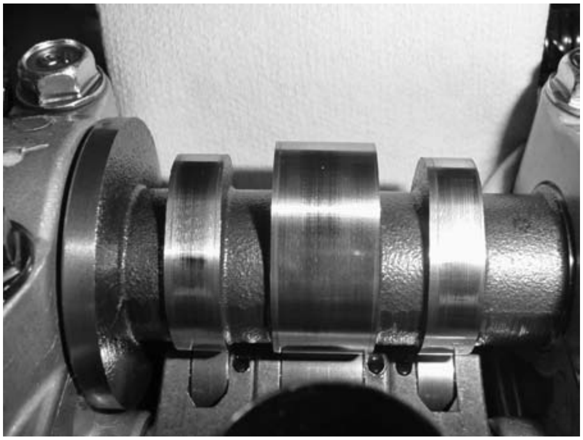


Figure 17–66 The three cam lobes of a VTEC engine. Shown left to right: ultra-low lift/duration lobe, high-lift/long-duration lobe, and primary lobe. (Photo courtesy of William K. Bencini.)

arms of a VTEC engine. Figure 17–66 shows the three cam lobes of a VTEC engine.

The PCM considers four inputs before energizing the VTEC oil solenoid (Figure 17–67). Engine RPM must be between 2300 and 3200 RPM on the four-cylinder application, must exceed 3500 RPM on 3.0-L applications, and must exceed 4900 RPM on certain Prelude applications. Vehicle speed must exceed 19 mph, coolant temperature must exceed 140°F (60°C), and the engine must be under appropriate load. Ultimately, at lower RPM, the cylinder operates with a single intake valve and a single exhaust valve, thus keeping the air flow velocity high for improved low-end response. But, at high RPM, the cylinder operates using two intake valves and two exhaust valves, all opening and under the control of a high-lift, high-duration cam lobe for maximum airflow.

VTEC-E. A VTEC-E is used on some applications; it is similar to the VTEC system except that a mid (connecting) rocker arm is not used. A single synchronizing piston within the primary rocker arm causes the primary and secondary rocker arms to be mechanically linked at high engine speeds.

i-VTEC. The i-VTEC, or intelligent VTEC, engine (Figure 17–68) combines the technology of the VTEC systems just discussed with the ability to rotate the intake camshaft to change valve overlap. Initially, i-VTEC technology was made available on two Honda vehicles: the 2002 Honda CR-V and the 2002 Acura RSX.

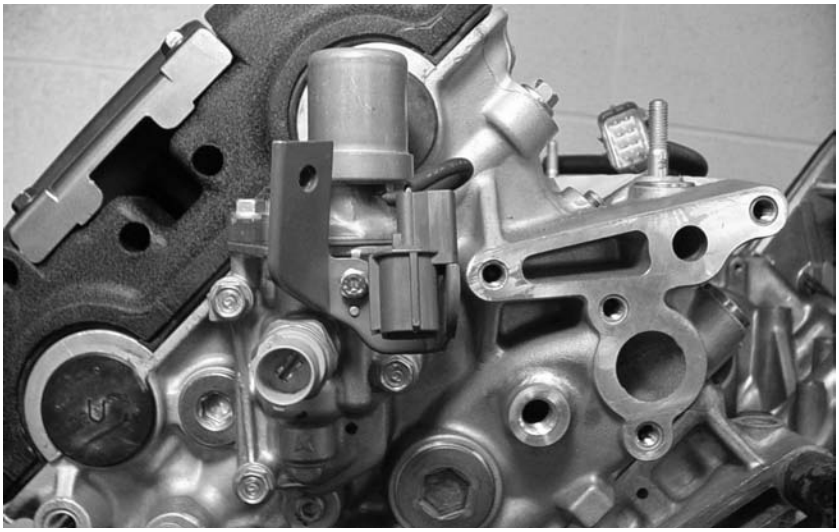


Figure 17–67 VTEC oil solenoid. (Photo courtesy of William K. Bencini.)

Figure 17–68 i-VTEC 2.4 L engine. (Photo courtesy of William K. Bencini.)

The variable valve-lift feature is accomplished by using two rocker arms and different camshaft profiles to change the opening of the valve. With a new "two rocker arm" design, only one valve is opened at lower engine speeds. This causes the intake air/fuel mixture to swirl, optimizing combustion for low RPM operation. At a predetermined RPM, oil pressure is used to lock together the two rocker arms, resulting in both valves opening together. However, now both valves follow the higher camshaft profile that the second rocker arm normally follows.

The variable timing valve feature is accomplished by the use of a computer-controlled variable camshaft actuator, or cam phaser (Figure 17–69), which can vary the intake camshaft up to 50 degrees in relation to the crankshaft. The PCM is able to direct oil pressure to one side or the other of the extending arms of the central unit, which, in turn, is keyed to the intake camshaft. This changes the relationship of the center unit

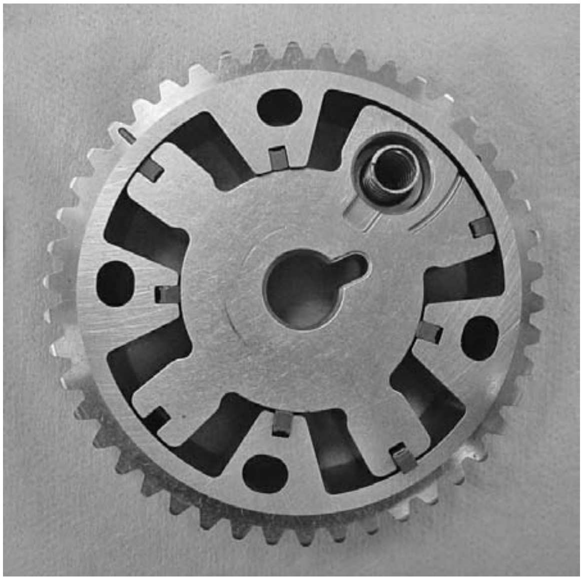


Figure 17–69 VVT actuator, or cam phaser. (Photo courtesy of William K. Bencini.)

to the outside toothed gear and, thus, changes the relationship of the intake camshaft to the crankshaft, ultimately advancing or retarding the camshaft's timing. Oil seals are installed on each of the two major components of this assembly where they contact each other.

The Modern i-VTEC Systems

Honda's term "i-VTEC" was used to describe a particular function, as described in the previous paragraphs. Today Honda uses this term to describe all of their modern engines, regardless of the function or functions available on that engine. There are four possible i-VTEC functions, of which up to three may be used on any given engine. They are:

1. Variable Lift and Duration (VLD)
2. Valve Timing Control (VTC)
3. Progressive Valve Operation (PVO)
4. Disable Valve Operation (DVO)

Variable Lift and Duration. The VLD function is equivalent to the original VTEC system described in the preceding paragraphs. During low speed operation, the primary rocker arm is released from the secondary rocker arm, and the primary rocker arm operates its valve off a normal lift and duration cam lobe. At high engine speeds, the primary rocker arm is locked to the secondary rocker arm so as to operate the primary rocker arm's valve off the secondary rocker arm's high duration and lift cam lobe.

Valve Timing Control. The VTC function is equivalent to the VVT function of the i-VTEC system described in the preceding paragraphs. The VTC cam phaser (Figure 17–69) is used to vary the timing of the intake camshaft in its relationship to the crankshaft. Honda engineers feel that their VTC system offers an advantage by varying the timing of the intake camshaft as compared to some manufacturers that vary the timing of the exhaust camshaft. Honda uses their VTC function to eliminate the need for an EGR system by retaining some of the exhaust gasses in the cylinder when needed.

Progressive Valve Operation. The PVO function is the ability of the PCM to disengage a primary rocker arm that operates a valve from a secondary rocker arm that is operated according to a cam lobe so as to provide an *idle mode* whereby the valve is not opened. The PVO system will open and close only one intake valve and one exhaust valve at engine speeds below 2500 RPM so as to keep the velocity of the air flow high, resulting in excellent low-end response. This also provides for *high swirl combustion* within the cylinder and allows for a leaner air/fuel ratio to be used during cruise. At engine speeds above 2500 RPM, the PVO rocker arms are locked together so as to open and close a second intake valve and a second exhaust valve. This provides more air flow when the engine demands it.

Disable Valve Operation. The DVO function is similar to the PVO function in that it can disable a valve's ability to operate. However, unlike the PVO function, the DVO function is used by the PCM to disable all valves' ability to open for a specific cylinder, thus providing for Honda's **Variable Cylinder Management (VCM)** function. The DVO/VCM function uses rocker arms (Figure 17–70) that are similar to those used in other Honda VTEC engines, except that the

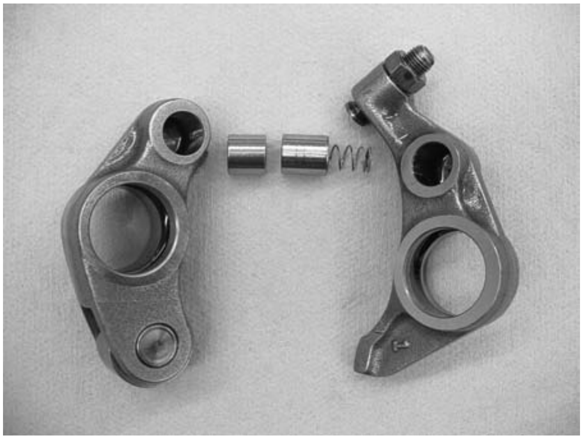


Figure 17–70 Rocker arms of a DVO system used with the VCM system on a 1.3-L Civic Hybrid. (Photo courtesy of William K. Bencini.)

synchronizing piston allows a rocker arm to engage an adjacent rocker arm to provide "valve-lift mode" (normal operation), or it may be retracted into itself to provide a "rocker arm idle mode." The latter mode effectively fails to open the intake and exhaust valves, thus leaving them closed and allowing the deactivated cylinders' pistons to act as air springs. This reduces the normal pumping losses. The fuel injector for the deactivated cylinders is also de-energized. The DVO/VCM function is used with both Honda's hybrid and non-hybrid applications.

Direct Gasoline Injection

Honda has now added direct gasoline injection technology to the i-VTEC engine and refers to the new engine as "i-VTEC I." This engine, using special engineering features, can be run during a lean cruise at air/fuel ratios as lean as 65:1, far surpassing the old 40:1 limit for direct-injection prototypes of the past. As with the original i-VTEC engine, only one intake valve is opened during low-load operation, causing a high-swirl effect as the fuel is injected into the cylinder. Ultimately, the i-VTEC I engine is capable of some markedly improved fuel economy while maintaining the responsiveness of a performance engine.

✔ SYSTEM DIAGNOSIS AND SERVICE

Prior to OBD II standardization, Honda PGM-FI systems were able to communicate memory DTCs to the technician through either one or four LEDs that were located on the PCM. With both LED designs, there was no need to *trigger* DTC output as with most other makes. Simply turning on the ignition switch to power up the PCM was all that was required to read DTC output on these early systems.

When one LED was used, turning on the ignition switch would result in a single flash that did not repeat if codes were not stored in the PCM's memory. If codes were stored in the PCM's memory, this was followed by repeated flashes of the LED to indicate the stored DTC(s). The total number of flashes represented the DTC. DTCs 1 through 15 were available, with 15 flashes of the LED representing DTC 15.

When four LEDs were used, they were numbered from left to right 8, 4, 2, and 1, similar to the base 10 values of binary code columns. The DTC number was interpreted by adding together the values of any illuminated LEDs. For example, if LEDs 8, 2, and 1 were illuminated, the DTC was code 11. The maximum DTC value was also a code 15.

In the early 1990s, Honda began making DTC output available through pulses of the MIL. This version required a jumper connection to be made at a test connector to trigger code output. This application allowed the PCM to illuminate the MIL if a fault within the system was sensed.

On OBD II applications, the PCM will illuminate the MIL by providing a ground and will set a DTC in an erasable memory if it senses a fault within the system. As with other OBD II vehicles, a scan tool may be connected to the diagnostic link connector (DLC); it is then used to pull DTCs from the PCM's memory along with freeze-frame data. Additionally, a scan tool may be used to look at data stream values, including sensor values and output commands. Prior to OBD II applications, Honda vehicles had no data stream capability. Therefore, scan tools were unable to communicate with the Honda PCM until Honda's first OBD II vehicle was introduced: the 1995 Accord with a V6 engine.

SUMMARY

To focus on Asian engine control systems in this chapter, we have studied late-model Nissan, Toyota, and Honda vehicles.

The chapter considered the different injection patterns (simultaneous and sequential) employed for start-up, patterns to avoid the use of a cold-start injector, and patterns to optimize emissions during the engine's dirtiest phase: start-up cranking. The different fuel enrichment strategies, as well as spark advance map alterations, were considered. We saw how self-learning capabilities allowed the systems to adjust fuel mixture and spark timing from recorded experience. And we considered the more elaborate fuel canister vapor absorption and storage systems. We learned the use of an EGR temperature sensor to monitor the effectiveness of the bypass valve's circuit.

We also took a closer look at the various versions of the Honda VTEC series engines, including the newest i-VTEC functions: VLD, VTC, PVO, and DVO/VCM.

▲ DIAGNOSTIC EXERCISE

A customer brings in a late-model Nissan with the check engine light on. There are no driveability complaints, either from the customer or noticeable to a technician on a test drive. When checked with the scan tool at the OBD II DLC, the computer indicates a problem in the charcoal canister purge system. What is the most likely cause of this problem? How long should the repair take if the most likely cause is the real one?

Review Questions

1. Technician A says that a throttle position sensor on a Nissan ECCS application returns a voltage back to the PCM from about 0.5 V at idle to as high as 4.6 V at WOT. Technician B says that some Nissan ECCS applications use an absolute pressure sensor to detect both ambient pressure and intake manifold pressure. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
2. How much voltage should Nissan's analog mass air flow (MAF) sensor return to the PCM at idle?
   A. 0.4 to 0.6 V
   B. 1.0 to 1.7 V
   C. 2.0 to 2.5 V
   D. About 4.0 V
3. What method is used on Nissan ECCS applications to monitor EGR flow?
   A. A pressure sensor is used to monitor the exhaust pressure just before the EGR valve but after a restriction placed in the exhaust tube.
   B. A pressure sensor is used to monitor intake manifold pressure while opening and closing the EGR valve during idle conditions.
   C. A temperature sensor is placed into the EGR passage.
   D. The oxygen sensor is monitored while opening and closing the EGR valve during idle conditions.
4. All *except* which of the following can result from a cylinder misfire?
   A. Production of too much CO_2 in the engine
   B. Overheating of the catalytic converter
   C. Catalytic converter failure
   D. Dumping of raw hydrocarbons into the atmosphere
5. Technician A says that some Nissan ECCS applications allow the PCM to electrically soften the dampening effect of the front engine mount to minimize engine vibration when the engine is idling. Technician B says on Nissan ECCS applications, the PCM may control the operation of the cooling fan. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
6. Fuel pressure on port fuel-injected Nissan applications will typically vary between which of the following?
   A. 9 and 13 psi
   B. 20 and 29 psi
   C. 34 and 43 psi
   D. 46 and 55 psi
7. What component has been added only to California versions of the Nissan Sentra to help it meet the state's super low emission vehicle (SULEV) rating?

A. Supercharger
B. Electrically controlled front engine mount
C. Rear heated oxygen sensor
D. Air-cleaning radiator

8. Which of the following meters should be used to monitor a mass air flow (MAF) sensor signal on a Toyota TCCS application?
A. Voltmeter
B. Hertz meter
C. Duty-cycle meter
D. Pulse-width meter

9. What method is used on Toyota TCCS applications to monitor EGR flow?
A. A pressure sensor is used to monitor the exhaust pressure just before the EGR valve but after a restriction placed in the exhaust tube.
B. A pressure sensor is used to monitor intake manifold pressure while opening and closing the EGR valve during idle conditions.
C. A temperature sensor is placed into the EGR passage.
D. The oxygen sensor is monitored while opening and closing the EGR valve during idle conditions.

10. An ohmmeter is used to test a camshaft sensor on a late-model Toyota TCCS application. With the meter's selector set to the 2K scale, a reading of 1.213 is seen on the display. Technician A says that this reading indicates that the camshaft sensor needs to be replaced. Technician B says that this reading indicates that the camshaft sensor's resistance is within specifications for a typical late-model Toyota. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

11. Technician A says that the fuel pump on a Toyota TCCS application is controlled by the ignition switch only and should always run whenever the ignition switch is turned to the run position. Technician B says that some late-model Toyotas use a returnless fuel-injection system with the pressure regulator located within the fuel tank. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

12. Technician A says that the EGR valve on a Toyota TCCS application is designed to open only during cold engine operation. Technician B says that the EGR valve on a Toyota TCCS application is operated electrically and does not use vacuum to operate. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

13. Technician A says that Toyota's VVT-i system allows the PCM to advance or retard the timing of the intake camshaft. Technician B says that if a front or side air bag is deployed on a newer Toyota, the PCM will de-energize the fuel pump relay. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

14. A 1998 Toyota comes into the shop with an engine performance complaint. Technician A says that the PCM on this vehicle has no ability to store DTCs in memory. Technician B says that the PCM on this vehicle will store DTCs in memory but that they have to be pulled using manual methods because this system is not designed to allow communication between a scan tool and the PCM. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

15. Honda's early PGM-FI system used an EGR Valve Lift sensor on top of the EGR valve. What is this sensor?
A. A potentiometer
B. An NTC thermistor

C. A piezoresistive sensor
D. A piezoelectric sensor

16. The "main relay" on a Honda PGM-FI is used to provide power to all *except* which of the following?
A. PCM
B. Cooling fan
C. Fuel injectors
D. Fuel pump

17. What is the primary purpose of Honda's Fuel Injection Air (FIA) control valve system?
A. To allow the PCM to control idle speed
B. To increase WOT engine performance
C. To reduce NO_x emissions
D. To increase fuel atomization

18. Technician A says that Honda's original VTEC system allows the primary and secondary intake valve rocker arms to be mechanically linked to a central high-lift rocker arm at high engine speeds. Technician B says that Honda's original VTEC system allows the PCM to control when the primary, secondary, and mid (connecting) rocker arms will be mechanically linked together. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

19. Technician A says that the PCM on late-model Honda PGM-FI applications controls alternator field current to control charging system output. Technician B says that some Honda applications allow the PCM to control throttle position electronically based on input from an accelerator pedal position (APP) sensor. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

20. Of the following Honda engines, which one is designed to operate during a lean cruise with an air/fuel ratio as lean as 65:1?
A. VTEC
B. VTEC-E
C. i-VTEC
D. i-VTEC I

Chapter 18

Alternative Power Sources

OBJECTIVES

Upon completion and review of this chapter, you should be able to:

☐ Understand the difference between a series-hybrid-drive and a parallel-hybrid-drive vehicle.
☐ Define the components and system features of Honda gasoline/electric-hybrid-drive systems.
☐ Define the components and system features of Toyota gasoline/electric-hybrid-drive systems.
☐ Define the components and system features of Ford gasoline/electric-hybrid-drive systems.
☐ Explain the basic principles and understand the advantages associated with a fuel cell vehicle.

KEY TERMS

Continuously Variable Transmission (CVT)
Fuel Cell Vehicle (FCV)
Grade Logic Control
High-Voltage (HV) Battery
Home Energy Station (HES)
Motor/Generator (MG)
Parallel Hybrid
Polymer Electrolyte Membrane (PEM)
Proton Exchange Membrane
Regenerative Braking
Series Hybrid

In an effort to dramatically increase fuel mileage and reduce CO_2 emissions, automotive manufacturers have designed power trains that incorporate a **motor/generator (MG)** that performs in combination with a gasoline engine to accelerate the vehicle. A motor/generator is defined as a component that can (a) turn electrical energy into mechanical energy (as a motor does) and (b) turn mechanical energy into electrical energy (as a generator does). In city driving, an electric motor has a great advantage over a gasoline engine in that it has the ability to develop its maximum torque beginning just above zero RPM. A gasoline engine must reach several thousand RPM to generate its maximum torque.

Essentially, hybrid gasoline/electric vehicles no longer have to be charged overnight, as a straight electric vehicle must be. Nor do they have a limited range between charges, as do straight electric vehicles. The gasoline engine runs to provide power to recharge the **high-voltage (HV) battery** when needed and can also assist the motor/generator to accelerate the vehicle when needed. Also, these vehicles use **regenerative braking** to return braking energy to the HV battery when coasting or braking. This prolongs the life of the hydraulic braking system hardware.

The distinction between these systems and the Chevrolet Silverado Hybrid FAS system described in Chapter 12 is that the hybrid systems discussed in this chapter utilize a hybrid drive system (dual-drive system), which uses both an electric motor and a gasoline engine to provide power to the drive train and drive wheels. The Silverado Hybrid FAS system does not use a motor/generator to power the drive train; rather, its only source of power for operating the drive train and drive wheels is the gasoline engine.

However, the Silverado is considered a mild hybrid in that it does use regenerative braking and does incorporate an auto stop/start feature on the gasoline engine, similar to the hybrids discussed in this chapter. Another similarity is that the Silverado Hybrid does use a motor/generator to start the engine and to recharge the 42-V system's batteries. But the Silverado's 42-V system does not have a voltage that is high enough to allow a motor/generator to actually move the weight of a large vehicle efficiently. And while the BAS system described in Chapter 12 does actually allow a 42-V alternator/starter to assist the gasoline engine somewhat in providing power to the drive train, its use is limited to smaller, lighter vehicles.

The hybrids described in this chapter use much higher voltages than the General Motors' FAS and BAS systems. Honda's mild hybrid operates at 144 V; the full hybrids operate at voltages from 300 to 650 V. In fact, the full hybrids use a voltage that is high enough that the motor/generator becomes the primary source of power to the drive train and drive wheels when the vehicle is operating at low speeds; the gasoline engine only runs to provide additional power to the drive train when it is needed or when the HV battery needs to be recharged.

The systems discussed in this chapter operate primarily as **parallel hybrids** in that the vehicles incorporating them can be accelerated using either an electric motor/generator (EMG) or the gasoline engine or both (Figure 18–1), thereby allowing the vehicles to take advantage of the characteristics of both power plants. However, some of these systems can also be operated as a **series hybrid** in that the gasoline engine can operate to cause a generator (or motor/generator) to provide additional electrical energy to the primary motor/generator to accelerate the vehicle (Figure 18–2).

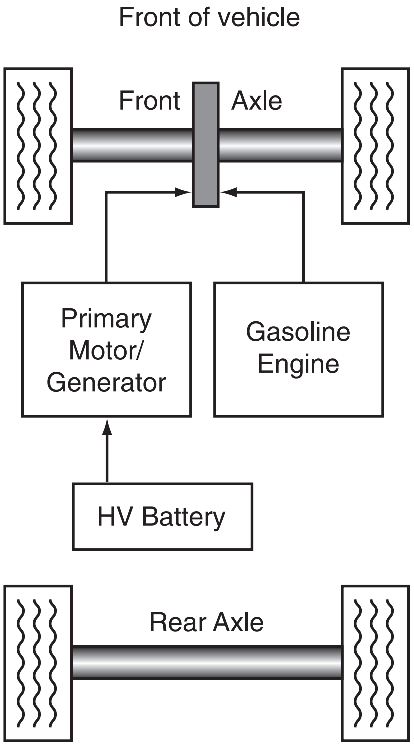


Figure 18–1 Power flow of a parallel hybrid drive vehicle.

WARNING: The high-voltage systems discussed in this chapter are only to be worked on by qualified service personnel who have been trained in the specific manufacturer training programs that pertain to these systems. Any attempt to diagnose or repair the high-voltage systems without the proper manufacturer training exposes the technician to a high potential for a fatal electric shock. Also, at the high voltages that are present in these systems, there is a very real threat of an electrical short creating either an arc flash, resulting in the release of tremendous thermal energy, or an arc blast,

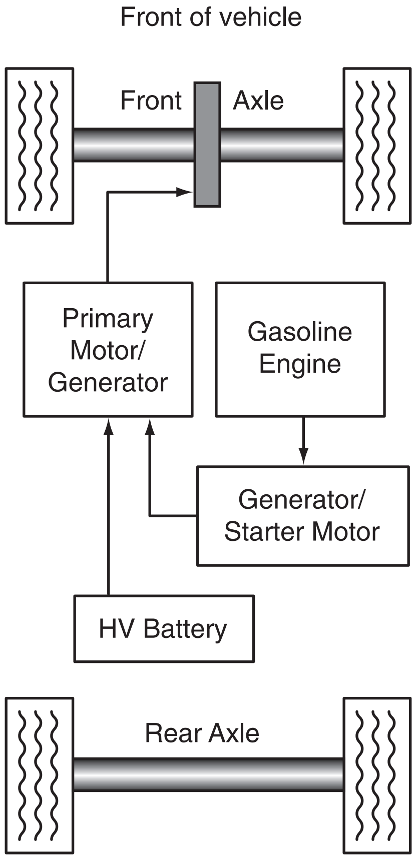


Figure 18–2 Power flow of a series hybrid drive vehicle.

> **resulting in the release of tremendous pressure. (An arc blast results from the instantaneous vaporization of copper, creating a rapid pressure expansion.) The discussion of the systems in this chapter is for informational purposes only and is not intended to provide the training that is required to work safely on these systems.**

A discussion of Honda's **fuel cell vehicle (FCV)** is also included in this chapter. This is another type of an electric vehicle; instead of using a gasoline engine in conjunction with a motor/generator to recharge the HV battery this vehicle uses hydrogen fuel cells to provide the electrical power that the motor uses to accelerate the vehicle's drive wheels.

HONDA INSIGHT, CIVIC, AND ACCORD HYBRIDS

Integrated Motor Assist

Honda gasoline/electric-hybrid-drive vehicles use a system called *Integrated Motor Assist (IMA).* This IMA system was first used on the Honda Insight (a vehicle that was manufactured as a hybrid only). The IMA system was then added to two mainstream Honda vehicles: the Honda Civic and the Honda Accord. The Honda Civic Hybrid and the Honda Accord Hybrid are offered alongside the standard gasoline engine versions of these vehicles.

The IMA system uses a single electric motor/generator (EMG) coupled with a gasoline engine to provide acceleration and cruising for the vehicle, as well as regenerative braking. Honda offers a choice of two transmissions—either a manual transmission or a **Continuously Variable Transmission (CVT).** The CVT transfers optimum torque either from the gasoline engine, from the electric motor, or from both to be applied to the front-drive wheels regardless of vehicle speed or load. As a result, the driver never has to "shift gears" as with normal multi-speed transmissions.

Honda's IMA system is considered to be a mild hybrid in that the gasoline engine is the primary power source to accelerate the drive wheels (Figure 18–3) and will always run except when the vehicle is stopped. The IMA system's single electric motor/generator (EMG) runs to assist the gasoline engine as the need arises. During acceleration and under heavy engine load, the EMG contributes considerable torque, resulting in both lower fuel consumption and powerful acceleration. At cruising speeds, when engine load is low, the EMG shuts down, allowing the gasoline engine to be the sole source of power. During deceleration and braking, the EMG converts the vehicle's kinetic energy into electricity to recharge

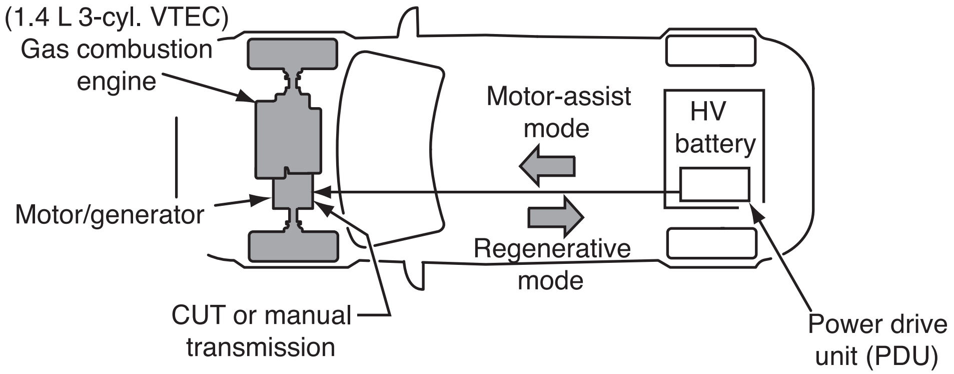


Figure 18–3 Honda IMA system (Insight).

the high-voltage battery (referred to as *regenerative braking).* The EMG also functions as a high-RPM starter motor to start the gasoline engine as needed. When stopping—as at a traffic light, for example—the gasoline engine shuts off and then restarts immediately when the driver steps on the accelerator pedal. This automatic idle-stop system contributes to both improved fuel efficiency and lower emissions.

The IMA system is composed of an ultra-thin DC brushless motor, a nickel-metal hydride (Ni-MH) battery, and a Power Control Unit (PCU). The IMA system's PCU and the HV battery are both located under the cargo compartment floor behind the rear seat. The HV battery in the Insight, the Civic Hybrid, and the Accord Hybrid all use 120 cylindrically shaped batteries (cells) that produce 1.2 V each for a total of 144 V DC. These batteries are relatively smaller and lighter than those in most other hybrid vehicles, a technology that Honda pioneered in its EV PLUS electric car. The high-voltage cables are bright orange to make them easily identifiable.

Insight

The Honda Insight was first introduced in the United States in early 2000 and is billed as the first gasoline/electric-hybrid-drive car offered in the United States. With EPA fuel economy ratings of 61 mpg city/70 mpg highway, this vehicle earns the highest fuel economy rating for any passenger car. However, in the interest of achieving these figures, the Insight is designed as a small two-seater passenger car weighing less than 1900 pounds. In addition to the IMA system's motor/generator, the Insight uses a tiny 1.0-L 3-cylinder VTEC gasoline engine that weighs only 124 pounds and can produce up to 67 horsepower at 5700 RPM. It also uses Honda's lean-burn technology to maximize fuel economy.

Civic Hybrid

The Honda Civic Hybrid was introduced in March 2002, marking the first time an existing nameplate had been offered with a gasoline/electric-hybrid-drive system. The Civic Hybrid qualifies as an Advanced Technology–Partial Zero Emission Vehicle (AT-PZEV). The EPA fuel economy ratings are 48 mpg city/47 mpg highway for an automatic CVT Civic Hybrid and 46 mpg city/51 mpg highway for the manual transmission version. In addition to the IMA system's motor/generator, the Civic Hybrid uses a small, newly developed 1.3-L 4-cylinder VTEC gasoline engine that can produce up to 86 horsepower. The new engine incorporates i-DSI lean-burn combustion technology combined with a VTEC *Variable Cylinder Management (VCM)* system.

The 1.3-L i-DSI lean-burn combustion technology uses an engine design that promotes rapid combustion with the use of two spark plugs per cylinder. This allows the fuel/air ratio to run quite lean without lean misfire occurring. Thus, fuel economy is further improved.

The VTEC VCM system uses rocker arms that are similar to those used in the Honda VTEC engines, except that the synchronizing piston allows a rocker arm to engage an adjacent rocker arm to provide "valve-lift mode" (normal operation), or it may be retracted into itself to provide a "rocker arm idle mode." The latter mode effectively fails to open the intake and exhaust valves, thus leaving them closed, allowing the deactivated cylinders' pistons to act as air springs. This reduces the normal pumping losses. The fuel injector for the deactivated cylinders is also de-energized. The 1.3-L i-DSI engine's VCM function can deactivate as many as three of its four cylinders during low power requirements and can thus achieve a reduction of engine friction of 50 percent during deceleration (as compared with the previous IMA system). This improves the vehicle's electrical regenerative efficiency and thereby increases fuel mileage even further.

Accord Hybrid

The Honda Accord Hybrid was introduced as a 2005 model, marking the first time a V6 was used in a hybrid in conjunction with an electric motor, thus giving the vehicle V8-like performance and exceptional fuel mileage. This hybrid utilizes Honda's third generation of IMA technology. With EPA fuel economy ratings of 29 mpg city/37 mpg highway, the Accord Hybrid's 3.0-L i-VTEC V6 and IMA system can produce a combined net peak horsepower of 255 while achieving near-peak torque across most of its operating range. In addition to the IMA hybrid system, the V6 in the Accord Hybrid also uses the VCM cylinder deactivation system when the need for sustained power is low. The VCM system deactivates the three cylinders on the rear bank. When operating in three-cylinder mode, engine vibration is reduced through use of an "active control engine mount," which compresses/extends an actuator in same-phase, same-period motion to dampen the engine's vibration. Similarly, an audio speaker creates an opposite phase sound (called "Active Noise Control") to provide a frequency-canceling effect. The Active Noise Control uses microphones that are placed in the front and rear of the passenger compartment to monitor the low frequency "booming" noise created by three-cylinder engine operation. It then generates a counter frequency sound wave through the vehicle's audio system that effectively cancels the booming noise. This makes for a quieter interior, thus leaving the driver unaware of changes in cylinder activation.

Grade Logic Control. The Accord Hybrid also uses a control module strategy called **Grade Logic Control** to reduce the need for the driver to compensate constantly at the throttle pedal for transmission upshifts and downshifts when driving on mountainous terrain.

For example, most vehicles use input only from the TPS and VSS to determine upshift and downshift points. As a result, on certain uphill grades the driver must depress the throttle pedal farther as the vehicle starts to lose speed in order to downshift and bring the vehicle back to the desired speed. However, the vehicle is then likely over-accelerating, requiring the driver to back off the throttle position to avoid an over-speed condition, at which point the transmission upshifts again and the vehicle speed begins to decrease again. In the case of a downhill grade, the driver is constantly downshifting to reduce vehicle speed and then upshifting again to avoid loss of too much vehicle speed. This is commonly known as "gear hunting."

Honda's Grade Logic Control strategy uses input from the accelerator pedal position (APP) sensor, vehicle speed sensor (VSS), and the brake applied switch. The control module also uses vehicle speed to determine rate of acceleration or rate of deceleration. It even monitors barometric pressure. As a result, the control module can figure out when the vehicle is on an uphill slope or a downhill slope. The control module then adjusts the engine speed and/or electric motor generator (EMG) output accordingly and also makes related adjustments within the CVT. This reduces the need for the driver to keep compensating with the throttle pedal when driving in mountainous terrain.

TOYOTA HYBRID SYSTEM

Toyota Prius

The Toyota Prius made its debut in Japan at the end of 1997 and was first offered in the United States and Canada as a 2001 model. The Prius is a front-wheel-drive vehicle that uses the Toyota Hybrid System (THS). A second generation of THS, known as THS-II, was introduced in the 2004 model year. With several improvements having been made, the 2004 Prius with THS-II runs cleaner than the original Prius, earning both SULEV (Super Ultra-Low Emissions Vehicle) and AT–PZEV ratings. At 2900 pounds, the Prius has interior and trunk space that is similar to that of a Corolla. With an 11.9-gallon fuel tank, the Prius, with EPA ratings of 60 mpg in the city and 51 mpg on the highway, can exceed 500 miles on a tank of fuel.

It is also worth noting that Toyota has licensed its hybrid system to Nissan, which introduced the technology on the 2006 Nissan Altima.

Major Components and Operation of the Toyota Hybrid System

High-Voltage Battery. A high-voltage (HV) battery is located in the forward area of the trunk, just behind the rear seat (Figure 18–4). The HV battery provides electrical energy to the drive train as required. The HV battery consists of multiple nickel-metal hydride (Ni-MH) cells that are connected in series.

In the original THS design (through the 2003 model year), there are 38 modules, each consisting of 6 cells (a total of 228 cells) at 1.2 V each for a total of 273.6 V DC. When the HV battery is being charged, the total voltage approaches 300 V DC. The cells are connected by a single contact connecting one cell to the next. While the cost of replacing the entire HV battery can be quite high, Toyota provides a 100,000-mile warranty on it.

The HV battery has an air flow cooling system. Fans within the HV battery assembly blow air across the battery's cells. The vent for this system is located externally on the left rear of the Prius. It looks like a trim decoration just forward of the rear window and just to the rear of the driver's door.

Auxiliary Battery. A 12.6-V auxiliary battery is located on the left side of the trunk. This battery provides electrical energy to systems other than the drive train—lighting and electronic control

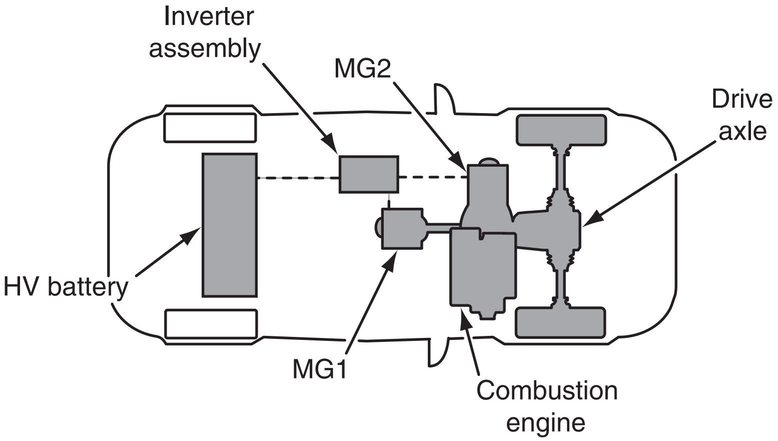


Figure 18–4 Toyota Prius components.

systems, for example. If the auxiliary battery has been drained (for example, by leaving the headlights turned on), it may be jump-started in the traditional method from a 12.6-V donor vehicle.

MG2. Unlike Honda's IMA system, the Prius uses a three-phase AC electric motor/generator (MG2) (Figure 18–4) to provide most of the power for light to moderate acceleration and for cruising up to 40 mph. MG2 uses electrical energy from the HV battery to create mechanical energy to accelerate the vehicle. MG2 also uses mechanical energy from the front-drive wheels during coasting and braking to create electrical energy to recharge the HV battery. With the original THS design, MG2 was rated at 30 KW or 44 horsepower and 258 foot/pounds of torque, with the maximum torque being achieved from 0 to 400 RPM.

INZ-FXE 1.5-L Gasoline Engine with VVT-i. The Prius uses the INZ-FXE 1.5-L four-cylinder gasoline engine with the Variable Valve Timing with intelligence (VVT-i) system. The engine is mounted transversely in the engine compartment on the passenger side of the vehicle (Figure 18–4). Through the 2003 model year, it was rated at 70 horsepower and 82 ft.-lbs. of torque. The engine is limited to 5000 RPM, thereby allowing the use of lighter components designed to improve efficiency. The engine also uses the Atkinson cycle, which retards the closing of the intake valves. This reduces cylinder pressures to an effective 9:1 compression ratio while allowing the power stroke to take full advantage of a 14:1 expansion ratio. This also reduces the engine's pumping losses.

The Atkinson cycle results in shifting the torque curve into a higher RPM range than a normal engine, resulting in increased fuel economy. While this design does not have much low-end torque for an initial acceleration from a stop, the motor/generator known as MG2 is more than capable of providing this initial torque.

Unlike Honda's IMA system, the Toyota gasoline engine is not the primary source of power for accelerating at low speeds but, rather, is a secondary source of power used to assist MG2 when the acceleration load requires it or when the HV battery needs to be recharged.

MG1. A second motor/generator known as MG1 (Figure 18–4) is used to start the gasoline engine when needed. Once the engine is running, MG1 acts as a generator to produce electrical energy. In other words, MG1 uses electrical energy from the HV battery to create mechanical energy to start the engine. MG1 also uses mechanical energy from the engine when it is running to create electrical energy, which is used to recharge the HV battery and to provide additional electrical power for MG2.

Inverter. The inverter is used to convert the HV battery's DC voltage to three-phase AC voltage to power either MG1 (to start the engine) or MG2 (to accelerate the vehicle). It also supplies MG2 with the AC voltage produced by MG1 during vehicle acceleration. The inverter is also used to convert AC voltage produced by MG1 (when the engine is running) or produced by MG2 (during coasting or braking) to DC voltage to charge the HV battery. The inverter is located above MG2 in the engine compartment. A separate cooling system and radiator are used to carry away excess heat from the inverter.

Converter. A voltage converter is used to reduce the voltage from the HV battery to charge the auxiliary battery. The converter is physically part of the inverter assembly.

High-Voltage Cables. The high-voltage cables that connect the HV battery to the inverter are a bright orange color. These cables should never be handled, except by properly trained service personnel, and then only after the HV battery has been properly disabled.

Planetary Gear Set. Due to an ingenious planetary gear set, which operates as a "power split device," the Prius can operate as a parallel hybrid vehicle, as a series hybrid vehicle, or both. As a parallel hybrid drive system, MG2, the gasoline engine, or both can be used to accelerate the vehicle. This allows the vehicle to take advantage of the characteristics of both power plants. When the gasoline engine runs, however, MG1 generates electrical energy, which can be used in addition to the HV battery's electrical energy to operate MG2, thus allowing

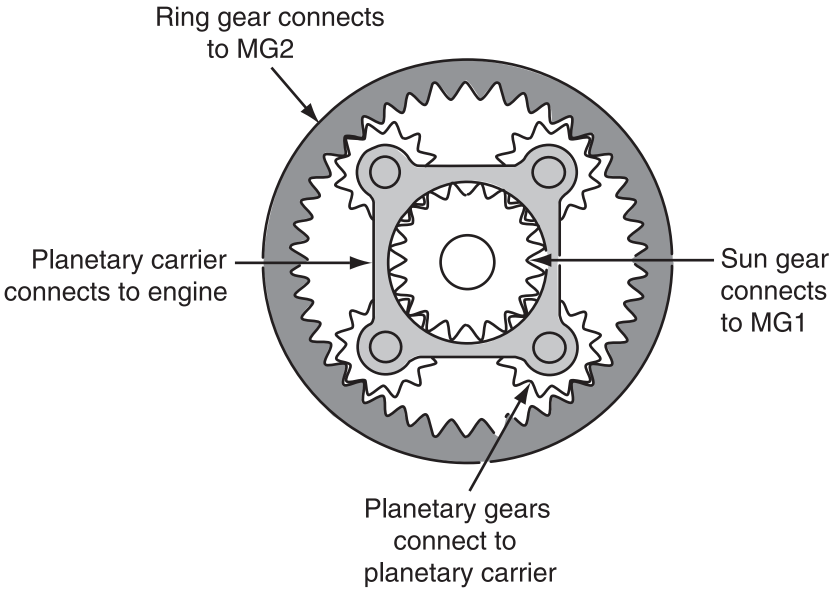

Ring gear connects to MG2
Planetary carrier connects to engine
Sun gear connects to MG1
Planetary gears connect to planetary carrier

Figure 18–5 Toyota Prius planetary gear set.

the system to act as a series hybrid. In fact, under heavy load the HV battery provides electrical energy to MG2 to drive the vehicle, the gasoline engine runs (causing MG1 to provide additional electrical energy to MG2 to drive the vehicle), and the gasoline engine also provides torque directly to the front-drive wheels, thus allowing the drive train to act simultaneously as a series hybrid and a parallel hybrid.

The planetary gear set (Figure 18–5), sometimes referred to as a clutchless single-speed transmission, actually acts as a CVT, allowing optimum torque either from the gasoline engine, from MG2, or from both to be applied to the front drive wheels regardless of vehicle speed or load. As a result, the vehicle never has to "shift gears" as with normal multi-speed transmissions.

Hybrid Electronic Control Unit. The hybrid electronic control unit (ECU) monitors and controls all of the power flow among all of the key hybrid system components, including the gasoline engine, MG1, MG2, and the HV battery. It is programmed to achieve optimum performance, efficiency, fuel economy, and emissions.

Initial Starting. After the ignition key is turned to "run," a "READY" indicator is displayed on the instrument panel. At this point, the gasoline engine may or may not begin running, depending on the HV battery's state of charge. In any case, once the "READY" indicator is displayed, the vehicle is ready to begin driving.

WARNING: When the ignition is turned on and the "READY" indicator is displayed, the engine will automatically begin running unexpectedly from time to time. If the hood is open, keep hands out of the area of the engine. And verify that the "READY" indicator is not illuminated when preparing to change the engine oil.

Regenerative Braking. During coasting or braking, MG2 acts as a generator, converting the mechanical energy from the drive wheels into electrical energy to recharge the HV battery. During this process, MG2 provides a deceleration rate that is similar to that normally experienced as a result of engine compression on a normal gasoline engine vehicle. If, during a hard stop, the required braking effort exceeds the capability of MG2 to slow the vehicle, then the hydraulic brakes are actuated. Also, if the control module determines that the HV battery is already fully charged, the required braking energy is dissipated through the hydraulic braking system. However, due to the regenerative braking design, not only is braking energy returned to the HV battery, thus improving city fuel economy, but the life expectancy of the braking system hardware is greatly increased.

Fuel Economy. Because MG2 is able to electrically provide the needed power required to operate the vehicle at lower vehicle speeds, the gasoline engine does not run when vehicle speed is less than 40 mph unless a hard acceleration requires more power than MG2 can provide or the HV battery needs to be recharged. However, the gasoline engine must run continuously when the vehicle is operated at highway speeds. When this design is coupled with the regenerative braking ability of this vehicle, the result is that the EPA fuel economy rating for city driving (60 mpg) is greater than that for highway driving (51 mpg).

Electronic Throttle Control. The Prius uses an electronic throttle control (ETC) system similar to that used by other manufacturers. In fact, because the Prius uses multiple power plants, it is necessary to use an ETC system. When the driver operates the throttle pedal, an APP sensor sends “driver demand” information to the control module, which then determines whether to operate the gasoline engine in addition to MG2.

Fuel Tank. With normal fuel tanks, putting 10 gallons of liquid fuel into the tank during refueling results in displacing 10 gallons of hydrocarbon vapors, most of which are pushed from the tank into the atmosphere during the refueling process. The Prius fuel tank incorporates an expandable bladder, which contains the supply of liquid gasoline used to operate the engine. As fuel is used, the bladder contracts within the tank assembly. As the tank is refueled, the bladder expands. This avoids storing excessive hydrocarbon vapors in the fuel tank, thereby greatly reducing the escape of hydrocarbon vapors to the atmosphere during refueling.

Second-Generation Toyota Hybrid System

The second generation of THS (THS-II) was introduced on the 2004 Prius. Also known as Toyota’s Hybrid Synergy Drive system, THS-II includes several improvements. The HV battery consists of only 28 modules, each consisting of 6 cells (total of 168 cells) at 1.2 V each for a total of 201.6 V DC. The cells are connected by dual contacts connecting one cell to the next to reduce the HV battery’s internal resistance. The THS-II design also uses a DC-to-DC boost converter to convert the 201.6 V DC to 500 V DC, which the inverter then changes to AC to power MG1 or MG2. This DC-to-DC boost converter is physically located within the inverter assembly. Also, because the auxiliary battery is located in the trunk, Toyota added a jump-start terminal to the junction block in the engine compartment to simplify connection of a battery charger or a set of jumper cables to start the system from a 12.6-V donor vehicle.

With THS-II, MG2’s rated horsepower is increased from 44 horsepower to 67 horsepower due to a stronger permanent magnet rotor with the motor/generator assembly and a higher voltage applied to the windings. This gives an increase in horsepower of about 50 percent. Also, while THS-II uses the same gasoline engine that the original THS used, its horsepower has been increased from 70 horsepower to 76 horsepower. The ability of MG1 to generate electrical current for use by MG2 and to recharge the HV battery is also increased due to an increase in its maximum RPM from 6500 to 10,000. Ultimately, the 2004 Toyota Prius with THS-II experienced a substantial increase in its “off-the-line” performance.

Other changes to the 2004 Prius include redesign of the radiator for the inverter’s cooling system to make it part of the radiator used in the engine’s cooling system, thereby increasing its effectiveness and compactness. A coolant heat storage capability also was added. A double-wall stainless steel container that has the ability to keep 3 L of coolant warm for up to three days is used to pre-warm the intake ports in the cylinder head prior to operating the gasoline engine during normal cold-start operating conditions (unless the engine must operate immediately following a cold start to provide additional power or to recharge the HV battery). This is designed to dramatically reduce cold-start emissions from the gasoline engine. The heat storage container contains both an electric heat pump that is under computer control and a temperature sensor.

A smart key system was added as an option in the 2004 model year. Antennas are placed in each door and the trunk, as well as within the instrument panel. If the vehicle key is within 24 inches of a door, the door will automatically unlock and allow the driver to operate the door handle to open the door, without having either to put the key into the lock cylinder or to push a button on a transmitter. The trunk can be opened similarly: If the vehicle key is within 24 inches of the deck lid's lock cylinder and antenna, the trunk release button will be enabled, even if the key is still in a pocket. If the key is in a pocket or in a purse on the front seat, the start button can be operated and the "READY" indicator will display, thus allowing the vehicle to be driven without having to put the key into the ignition switch.

Toyota Highlander Hybrid

Billed as the world's first seven-passenger electric/gasoline hybrid SUV, the Highlander Hybrid was introduced by Toyota as a 2006 model. Like the Honda Civic and the Honda Accord, the Toyota Highlander was an existing nameplate that was converted to hybrid-drive technology. This SUV incorporates the THS-II system (Toyota's Hybrid Synergy Drive system) used on the 2004 and newer Prius, with a few minor changes, earning a SULEV (super ultra-low emissions vehicle) designation. The Highlander utilizes a 3.3-L V6 gasoline engine (instead of the 1.5-L four-cylinder engine that the Prius used). When combined with the power of MG2 (and the high voltage provided to MG2 by the boost converter), this power train provides "off-the-line" performance similar to a V8. Toyota's internal tests indicate a 0-to-60 mph time of only 7.3 seconds on the four-wheel-drive with intelligence (4WD-i) model.

The 4WD-i version adds one additional motor/generator at the rear drive axle, known as Motor/Generator Rear (MGR). MGR does for the rear-drive wheels what MG2 does for the front-drive wheels. MGR uses power from the HV battery to accelerate the rear wheels but also uses regenerative braking from the rear wheels to charge the HV battery. MGR generates 96 ft.-lbs. of additional torque.

The HV battery is located under the second row seat (the third-row seat is standard equipment). It consists of 240 Ni-MH cells at 1.2 V each for a total of 288 V DC. This voltage is supplied to all three motor/generators through the boost converter and inverter assembly. The boost converter boosts this voltage and then sends it to the inverter, which then converts it to 650 V AC. This voltage is also used to power an electric air-conditioning compressor.

FORD ESCAPE HYBRID

Ford applied hybrid-drive technology to the Ford Escape beginning in the 2005 model year. Like the Honda Civic, the Honda Accord, and the Toyota Highlander, the Escape is available either with a standard gasoline engine and drive train or with the hybrid-drive technology. The Ford Escape became the first SUV to get the hybrid-drive technology. The Escape Hybrid has an EPA fuel economy rating of 36 mpg city/31 mpg highway and is labeled as a Partial Zero Emissions Vehicle (PZEV). The Escape Hybrid is available as a standard front-wheel-drive vehicle or with an intelligent four-wheel-drive system. For 2006, Ford also introduced the hybrid-drive system on the Escape's Mercury counterpart, the Mercury Mariner (introduced in the fall of 2005). Ford Motor Company developed Ford's hybrid technology, but because Ford and Toyota do share certain licenses with each other, several similarities are found in Ford's hybrid-drive technology and Toyota's, though there are several differences as well.

The Escape Hybrid uses an electronically controlled Continuously Variable Transmission

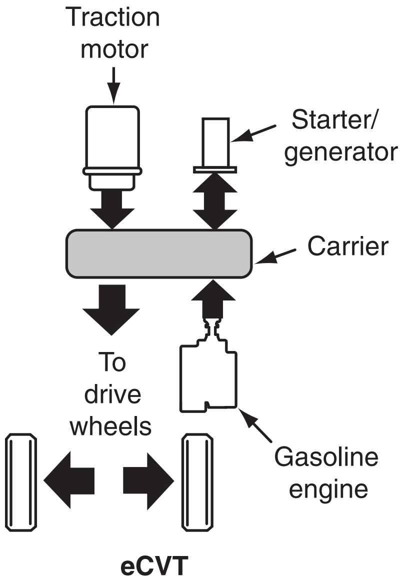


Figure 18–6 Ford Escape Hybrid primary components.

(eCVT) that consists of a planetary gear designed to split the power, as in the Toyota system (Figure 18–6). The *starter/generator* is equivalent to Toyota's MG1 and is used to start the gasoline engine as needed. Once the engine is running, the starter/generator produces voltage to charge the high-voltage (HV) battery and to help power the *traction motor.* The traction motor is equivalent to Toyota's MG2 and uses voltage from the HV battery and from the starter/generator to drive the drive wheels through the output shaft. During deceleration and braking, the traction motor uses the vehicle's kinetic energy to produce voltage to recharge the HV battery (regenerative braking).

Like Toyota's MG2, the Escape's traction motor is the primary source of power to the drive wheels when accelerating and when cruising at low speeds. The gasoline engine runs as needed to assist the traction motor, to recharge the HV battery, or when the vehicle is cruising at higher speeds.

The engine used in the Escape is a 2.3-L four-cylinder that uses the Atkinson cycle. By delaying the closing of the intake valves to about 90 degrees ABDC (instead of the 40 degrees ABDC designed into many engines), the engine is able to shift the torque curve higher to increase fuel economy. Essentially, the compression stroke is effectively a short stroke while the power stroke takes advantage of the engine's full compression ratio, becoming effectively a long stroke. While this type of camshaft does not do well for quick starts "off the line," the traction motor provides the needed initial torque for such acceleration.

The PCM will lean out the fuel injectors' pulse width for two or three crankshaft rotations just prior to shutting down the gasoline engine. This is referred to as a "lean engine shutdown" and is done to ensure that the Atkinson cycle engine does not release excessive hydrocarbons into the atmosphere by way of the intake manifold due to the late-closing intake valves. During this lean engine shutdown, the engine will stumble slightly. The engine is equipped with active powertrain mounts that reduce the vibration felt in the passenger compartment during engine shutdown.

The HV battery consists of 250 1.2-V Ni-MH batteries connected in series to produce 300 V DC. An inverter converts this voltage to AC for use by the traction motor or the starter/generator. The HV battery assembly is located below the floor of the rear cargo area. A power disconnect switch on top of the HV battery assembly is rotated to electrically open the high-voltage circuit by dividing the battery electrically at its midpoint (Figure 18–7). As on the Toyota and Honda hybrids, all of the high-voltage cables are bright orange. The following are some of the differences between the Escape and Toyota systems:

- The Escape's high-voltage connectors incorporate a third wire that signals the battery control module to open the high-voltage battery at its midpoint if the high-voltage wire is disconnected improperly prior to properly opening the high-voltage circuit.
- The Escape utilizes two inertia switches—one located at the front of the vehicle and one located at the rear of the vehicle—that open upon impact, as during a vehicle accident.

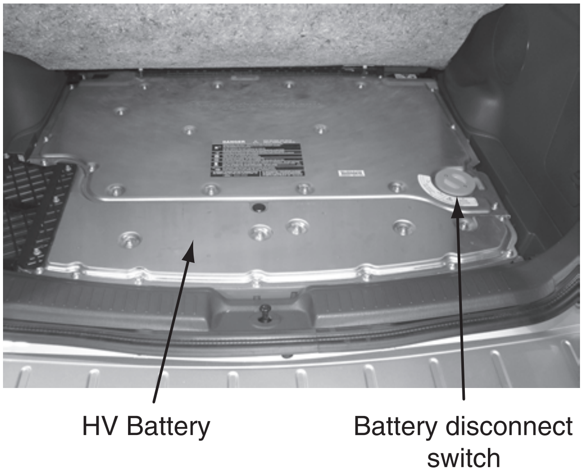


Figure 18–7 Ford Escape battery disconnect switch.

The rear inertia switch is an input directly to the battery control module. The front inertia switch is an input to the PCM. If the PCM sees that the front inertia switch has opened, it relays this information to the battery control module. If an accident causes either inertia switch to open, the battery control module opens the high-voltage circuit by electrically dividing the HV battery at its midpoint.

- While the Escape also uses two cooling fans to blow air through the HV battery assembly for cooling, it also uses "opportunistic cooling" to provide refrigerated air from the climate control system to cool the HV battery assembly any time the driver has requested A/C operation for passenger compartment cooling. This allows the HV battery to be cooled below its normal operating temperature, which may delay having to run the engine again just to cool the HV battery.

The Ford Escape Hybrid also uses Electronic Power Assist Steering (EPAS). This system varies the level of power steering assist electronically; it can draw up to 80 amp at parking lot speeds when maximum assist is required.

The Ford Escape's Electro-Hydraulic Brake (EHB) system allows a control module to interpret how much deceleration is to be achieved through the regenerative braking system and how much is to be achieved through the hydraulic braking system. The brake pedal has a "pedal feel" emulator that allows the feel of the brake pedal to seem normal to a driver while the computer uses the electronics to control braking. In the event of electronic failure, the vehicle reverts to full hydraulic braking. The brake control module always applies the rear brakes slightly on all stops to create a slight drag at the rear of the vehicle while braking; the front brakes may or may not be used while braking, depending on the severity of the braking situation and the ability of the regenerative braking system to slow the vehicle. As a result, it is likely that the rear brakes on the Escape will wear out long before the front ones do—just the opposite of a normal vehicle. Also, the brake control module powers up from time to time to move fluid around within the braking system even with the vehicle at rest and parked in a garage.

FUEL CELL VEHICLES

Another version of an electric vehicle that never has to be plugged in to be recharged overnight is one that generates its own electricity on board using hydrogen fuel cells. This type of vehicle is referred to as a Fuel Cell Vehicle (FCV). Sir William Robert Grove (1811–1896) first invented fuel cell technology in 1839. He determined that if the charging of a battery (sending electrical current through water) could turn the water in the electrolyte into oxygen and hydrogen, then there must be a way to perform this function in reverse—that is, through the combining of oxygen and hydrogen, water and electron current flow could be produced. In the 1960s, the technology was used to provide electrical power on spacecraft in the Gemini and Apollo space programs. During the 1980s, automobile manufacturers began working on applying fuel cell technology to automotive applications. In fact, a *hydrogen highway* has already been set up along the West Coast of the United States, with hydrogen refueling stations from Mexico to Canada. The city of London, England, has already begun using busses powered by hydrogen fuel cells and, in 2005, began replacing 600 diesel-powered busses with such busses each year. Their expectation is that their entire fleet of 7500 busses used for public transportation will be powered using fuel cell technology by the year 2012. London's municipal bus network is one of the largest and most comprehensive transportation systems in the world. The 7500 London busses carry 5.4 million passengers on more than 700 different routes on a daily basis. London's entire fleet of busses will soon consist of zero-emission FCVs. London will also replace many of their police cars and ambulances with FCVs by 2009.

Fuel Cells

Several types of fuel cells (distinguished by the type of electrolyte used) have been created. Honda, Ford, Toyota, and General Motors are using **Polymer Electrolyte Membrane (PEM)** fuel cells. These fuel cells are also commonly known as **Proton Exchange Membrane** fuel cells (Figure 18–8). PEM fuel cells were first used in the Gemini space program. PEM fuel cells use solid polymer membrane (a thin plastic film) as an electrolyte. PEM fuel cells combine hydrogen (H_2) with oxygen (O_2) from atmospheric air to create electrical current flow. The only emissions resulting from fuel cell operation are water (H_2O) and heat. A hydrogen atom has a single electron orbiting around a single proton in its nucleus and contains no neutrons. If hydrogen is brought to one side of the membrane and oxygen is brought to the other side, the hydrogen is attracted to the oxygen. However, the membrane will allow only the hydrogen atoms' protons to pass through it

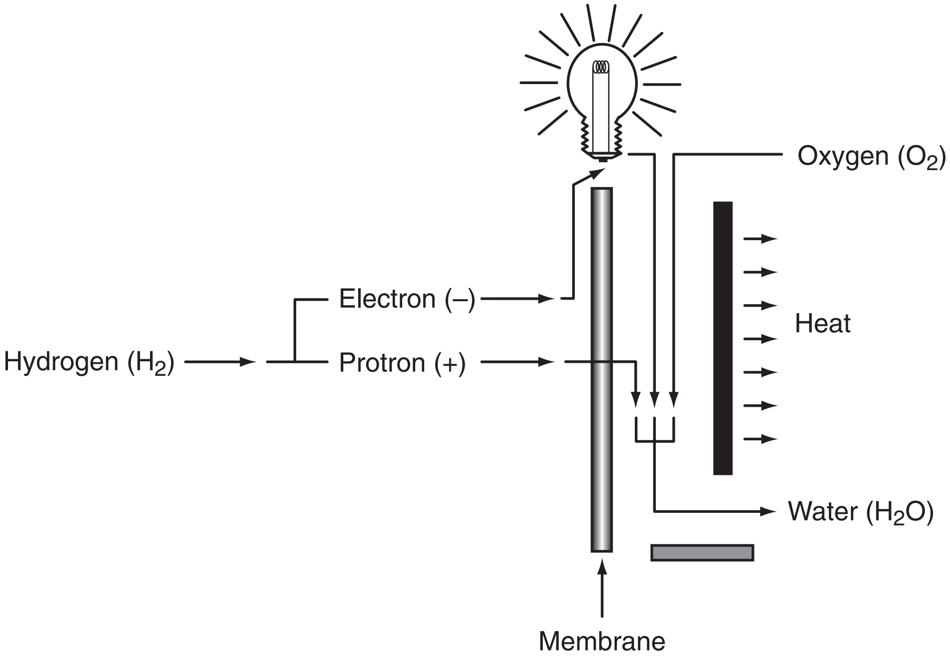


Figure 18–8 PEM fuel cell.

(thus the name Proton Exchange Membrane). The hydrogen atoms' electrons cannot pass through the membrane but must be directed through another path to get to the other side, thus generating electrical current flow.

PEM fuel cells are capable of generating a very powerful electric current, ranging from 1 W to 250 KW, depending on their physical size. Fuel cells are grouped together to create fuel cell stacks. PEM fuel cells are capable of operating at relatively low temperatures (less than 212°F or 100°C). The resulting emissions of a PEM fuel cell are only heat and water. No toxic emissions are produced. Nor does a PEM fuel cell produce any CO_2 emissions.

Another advantage of powering a vehicle by using hydrogen to generate electricity via a fuel cell is the high energy efficiency that is realized (about 83 percent efficiency) when compared to the efficiency of a gasoline engine (typically considered to be between 30 percent and 40 percent).

The hydrogen consumed by a PEM fuel cell can be obtained from several different sources including water, gasoline, methanol, and magnesium. For example, a *reversible fuel cell* can be used to turn liquid water into separated oxygen and hydrogen by applying a small voltage to it. Then this same fuel cell can be used to turn the same oxygen and hydrogen back into water, creating electrical power in the process. Unfortunately, when the total wattage (power) is considered, there is a net power loss in this process. But there are still some advantages: If electrical power generated from coal can be used to obtain the hydrogen, the dependence on oil is still lessened; and it is easier to control emissions from a stationary power plant than it is to control them on a moving vehicle. But the real advantage can be realized if a renewable energy resource can be used to create the electricity that is used, in turn, to extract the hydrogen from its original compound—resources such as solar power, hydro power, and wind power. (For some experiments relating to the information in this paragraph, a reversible PEM fuel cell, electronic board, and model car can be purchased from a company called "The Fuel Cell Store" at *http://www.fuelcellstore.com;* click on "Educational.")

Honda FCX

The Honda FCX (Fuel Cell Power) is an electric vehicle that uses PEM fuel cell stacks to power the electric motor/generator (EMG) that accelerates the drive wheels. Honda has already leased or sold several of these to cities for use in their fleets on U.S. roads. Because the resulting output of the PEM fuel cell stack is only heat and water, the Honda FCX is rated as a Zero Emission Vehicle (ZEV). The EPA mileage ratings on the FCX, in "miles-per-kilogram of hydrogen consumed," are 51 city and 48 highway. The maximum speed of the FCX is limited electronically to 95 mph.

Honda first introduced two FCV prototypes in 1999: the FCX-V1 and the FCX-V2. In 2000, Honda introduced a third FCV prototype (FCX-V3) at the California Fuel Cell Partnership in Sacramento, California. In 2001, Honda introduced the fourth FCV prototype (FCX-V4) and also designed the first solar-powered hydrogen production and refueling station, which was built in southern California. In 2002, the 2003 Honda FCX became the world's first FCV to be certified by the EPA and CARB. Also in 2002, the city of Los Angeles leased two Honda FCX vehicles. In 2003, Honda began building its PEM fuel cell stacks using a Honda proprietary membrane that allows it to begin operating at subzero temperatures. Also in 2003, the city of Los Angeles leased three additional FCX vehicles.

Honda also began working on designing a hydrogen **Home Energy Station (HES)** in 2003. In 2004, Honda began experimental operation of the first HES. This came about because automotive manufacturers discovered, as a side note, that people who owned the early straight electric cars enjoyed being able to charge them at home and, as a result, never had to visit a refueling station. Today the HES has been reduced to a size that can be hung on a garage wall and can use tap water with electricity from a wall outlet to create the hydrogen needed to refill a vehicle's hydrogen tanks overnight.

In 2004, the city and county of San Francisco took delivery of two Honda FCX vehicles, and two additional FCX vehicles went to the State of New York. In February 2005, Honda announced that the city of Las Vegas, Nevada, also was leasing two FCX vehicles. As of February 2005, the number of Honda FCX vehicles on U.S. roads stands at 14.

The Honda FCX uses an electric motor/generator (EMG) to accelerate the front wheels and to provide regenerative braking capability. The Ni-MH HV battery of the THS and THS-II systems has been replaced by an "ultra-capacitor," a unit that consists of many smaller, high-efficiency capacitors that provide a high-energy storage capability (Figure 18–9). The fuel cell stacks, capable of producing 78,000 W of power, are located below the main floorboard of the vehicle. Two high-pressure hydrogen storage tanks are located just beneath and behind the rear seat. A liquid cooling system is provided for the fuel cell stacks, using one large radiator. (Two additional smaller radiators are placed one on either side for cooling of drive train components.) A Power Control Unit (PCU) controls the operation of the fuel cell stacks to keep the ultra-capacitor properly charged. During cruising and mild acceleration, output to the EMG is provided directly (and only) from the fuel cell stacks. During start-up and moderate to heavy acceleration, the ultra-capacitor provides the EMG with additional electrical power to assist the fuel cell stacks, resulting in crisp acceleration. During braking or coasting, the EMG uses regenerative braking to recharge the ultra-capacitor. To conserve hydrogen fuel, the PCU shuts down the fuel stacks when the vehicle is stopped. When the vehicle is stopped, electrical energy to operate the electric A/C compressor and other vehicle electrical systems is provided by the ultra-capacitor.

Output Density of a Ni-MH Battery versus an Ultra-Capacitor. This is Honda's second version of the ultra-capacitor. The output of the THS/THS-II systems' Ni-MH HV battery is limited to approximately 900 W per kilogram (W/kg) due to the effects of heat loss. The ultra-capacitor's low resistance enables it to handle much higher output. The ultra-capacitor used on current FCX vehicles further improves the performance of the previous model, achieving an output density of 1750 W/kg or more.

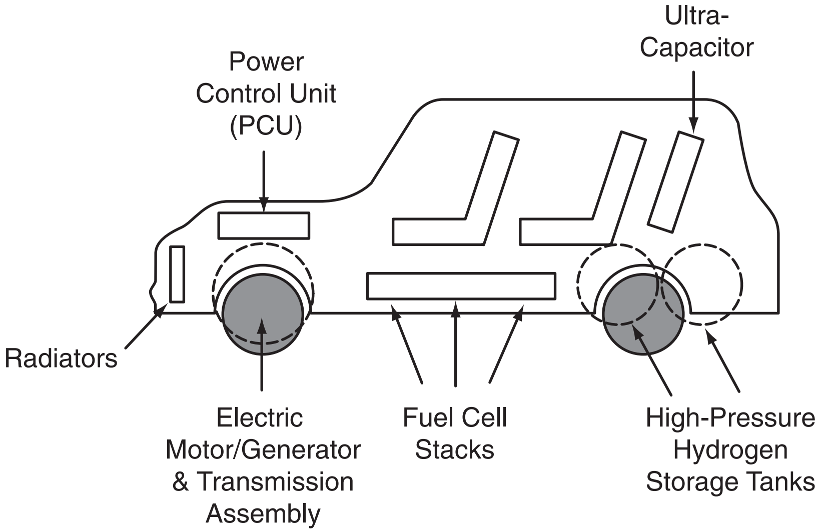

Ultra-Capacitor
Power Control Unit (PCU)
Radiators
Electric Motor/Generator & Transmission Assembly
Fuel Cell Stacks
High-Pressure Hydrogen Storage Tanks

Figure 18–9 Components of the Honda FCX.

Ford Focus FCV

Ford Motor Company has adapted the Ford Focus to become a fuel cell vehicle prototype, known as the Ford Focus FCV. Like the Honda FCX, the Ford Focus FCV uses PEM fuel cell technology. The system supplies up to 330 amp at between 250 and 400 V with a nominal voltage of 315 V. Similar in concept to the Honda FCX, the Ford Focus FCV is also awarded a ZEV rating. The maximum speed of the Focus FCV is electronically limited to 80 mph.

Toyota FCHV

In December of 2002, Toyota began limited marketing of Toyota's fuel cell vehicle, known as the Fuel Cell Hybrid Vehicle, or FCHV, in the United States and Japan. Toyota bills the FCHV as the "closest thing yet to the ultimate eco-car." Toyota is also using the Toyota fuel cell stack in a wide variety of applications including city busses, small cars, and even fuel cells for applications in the home.

General Motors Fuel Cell Vehicles

General Motors has a couple of fuel cell prototype vehicles—the HydroGen3 and the Hy-wire. Both vehicles demonstrate GM's expertise in fuel cell technology. These vehicles utilize a fuel cell stack that can produce 94 KW of available power and are capable of a top speed of 99 mph.

The GM Hy-wire, known as the *Autonomy,* is the world's first vehicle to combine fuel cell technology (to power the drive train) with control-by-wire technology. The Autonomy was displayed at the 2002 North American International Auto Show in Detroit, Michigan. The fuel cell stacks, hydrogen tanks, batteries, control modules, and four EMGs—one at each wheel—are contained within an 11-inch-thick chassis which has a skateboard-like appearance. In fact, the Autonomy has become known as the *skateboard.* The Autonomy's design means that there is no gasoline engine, and interior space is maximized. Ultimately, it can accommodate five occupants as well as some cargo depending upon the body that is attached to it.

The Autonomy, because it uses drive-by-wire, steer-by-wire, and brake-by-wire systems, can be electronically programmed to accommodate the characteristics of any type of vehicle body that is attached to its skateboard chassis. Even the suspension can be electronically tuned. The driver has no pedals to operate. The driver's controls are contained in a single module, called the *driver control unit,* that can be easily configured to either a left-hand drive (as in the United States and Canada) or a right-hand drive (as in Australia) position. The driver control unit allows the driver to control the throttle, the steering, and the braking of the vehicle and may allow him/her to control other vehicle systems electronically as well.

Fuel Cell Summary

In the future, expect to see an increase in fuel cell vehicles as the technology progresses and prices become more affordable. As more manufacturers begin producing fuel cell vehicles, the number of available models will increase. Also expect to see the ability to refill the hydrogen fuel tanks in home garages using an HES.

FLEXIBLE FUEL VEHICLES

General Concepts

Today's Flexible Fuel Vehicle, or FFV, is designed to run on straight gasoline, a mixture of 90 percent gasoline with 10 percent ethanol, or a mixture of 15 percent gasoline with 85 percent ethanol known as *E85*. The components of the fuel management system on an FFV are updated (in terms of the materials they are constructed of) to be able to handle the extra ethanol content of E85 fuel: Chrysler states that the fuel system components must be upgraded to stainless steel. But the primary change is the additional ability of the PCM to be able to determine the fuel's composition. In other words, the PCM must be able to determine what percentage of fuel in the fuel tank is gasoline and what percentage is ethanol, even if the driver had a partial tank of gasoline that was topped off with E85 or a partial tank of E85 that was topped off with gasoline. Early FFVs use an add-on hardware type fuel composition sensor. Later FFVs simply use a software type fuel composition sensor that involves a "smarter" PCM with added programming that allows it to determine the fuel's composition.

Hardware Type Fuel Composition Sensor

There are currently several patents held by the major manufacturers for hardware type fuel composition sensors. These sensors include types such as optical sensors as well as sensors that measure energy vibration that becomes absorbed by the fuel. These sensors tend to be somewhat pricey, typically around $600, when you find that you need to replace a failed unit. Chrysler used a hardware type fuel composition sensor on their early FFVs called a "Smart Sensor." While these hardware type sensors are currently in use, they are beginning to be phased out and replaced with software type fuel composition sensors.

Software Type Fuel Composition Sensor

In 1998, Chrysler began replacing their hardware type fuel composition sensors with a software replacement within the PCM. Their computers' advanced programming allowed Chrysler engineers to remove the "Smart Sensor" from the system, performing the same task using a software program within the PCM. This, in turn, resulted in reducing the cost of the FFV system. General Motors' engineers also introduced a software type sensor on the Chevrolet Impala. The PCMs on these systems use input from the oxygen sensor and the fuel trim program along with complex algorithms that involve informing the PCM when the tank is refueled.

Ultimately, when the tank is refueled, the PCM will perform some tests involving its control of the air/fuel ratio in order to determine what percentage of the fuel is gasoline and what percentage is ethanol. The premise of these tests is that ethanol fuel contains oxygen and will cause the oxygen sensors to read leaner than pure gasoline does. You may recall that ethanol has been classified as an oxygenated fuel and has been added to gasoline in smaller concentrations (10 percent) for the purpose of reducing CO emissions for several decades.

The software type fuel composition sensors should continue to replace the hardware type sensors and should ultimately help to reduce the price of these vehicles, as well as eliminate one more piece of hardware that can fail.

✔ SYSTEM DIAGNOSIS AND SERVICE

WARNING: As stated previously, the high-voltage systems discussed in this chapter are to be worked on only by qualified service personnel who have been trained in the specific manufacturer training programs that pertain to these systems. Any attempt to diagnose or repair the high-voltage systems without the proper manufacturer training exposes the technician to a high potential for a fatal electric shock. Also, at the high voltages that are present in these systems, there is a very real threat of an electrical short creating either an arc flash, resulting in the release of tremendous thermal energy, or an arc blast, resulting in the release of tremendous pressure. (An arc blast results from the instantaneous vaporization of copper, creating a rapid pressure expansion.) The discussion of the systems in this chapter is for informational purposes only and is not intended to provide the training that is required to work safely on these systems.

One of the first steps in performing any service work on these vehicles is to follow the manufacturer's recommendations for disconnecting the HV battery (or ultra-capacitor). These procedures typically include the following steps:

1. Wear an electrically insulating glove on the hand that is used to disconnect power.

2. Keep the other hand in your pocket, not on the vehicle.
3. Use the hand with the electrically insulating glove to pull the "power disconnect plug" or to rotate the "power disconnect switch" (depending upon manufacturer) that is located in the trunk. (This procedure will electrically divide the HV battery in half as well as open the circuit.)

It should also be noted that when a technician who has had proper manufacturer training is working on one of these vehicles, all other technicians should stay clear of the vehicle, providing at least a three-foot safety zone around all sides of the vehicle. Also, all manufacturers of these vehicles provide information for emergency medical service personnel regarding how to safely extricate a trapped occupant from one of these vehicles following a collision, as well as information on how to respond if someone has received an electrical shock from one of these vehicles.

SUMMARY

In this chapter we have discussed alternative power sources that are already found on several mainstream vehicles, including these:

- hybrid-drive technology that uses a gasoline engine as the primary power source and an EMG to assist it as required
- hybrid-drive technology that uses an EMG as the primary power source at low speeds and a gasoline engine to assist it as required
- electric-drive vehicles that use fuel cell technology to provide the needed electric power

We have also taken a look at several other technologically advanced systems, including regenerative braking, Grade Logic Control, and Variable Cylinder Management (VCM). And we have discussed Flexible Fuel Vehicles (FFVs) that are able to burn E85 fuel as well as gasoline. All the systems discussed in this chapter are designed to substantially increase fuel mileage and reduce CO_2 emissions while continuing to provide acceptable performance. In the near future, you should expect to see dramatic increases in the following:

- the number of makes and models that utilize the technology discussed in this chapter
- the number of vehicles on the road that are equipped with the systems discussed in this chapter
- the number of vehicles that will come in to your service and repair facility that are equipped with the systems discussed in this chapter

The vehicles discussed in this chapter are just the beginning of a technological revolution that is changing the way a technician must approach a vehicle that has come in for service. For the technician who understands that upgrade training classes, textbooks, and other training materials are becoming increasingly important to his/her success in the industry, this technological revolution is not something to shy away from, but, rather, is the chance to pull ahead of the competition.

▲ DIAGNOSTIC EXERCISE

A customer has had his Toyota Prius towed to your service and repair facility with the "Output Control Warning Light" illuminated. Your service advisor asks you if you can take a look at it. What is the best course of action for you to take?

Review Questions

1. What is the advantage of an electric motor over a gasoline engine when driving in city traffic?
   A. An electric motor can develop higher horsepower than a gasoline engine can be designed to develop.
   B. An electric motor can develop its maximum torque beginning just above zero RPM.

   C. An electric motor can develop its maximum torque beginning at about 1500 RPM.
   D. An electric motor can develop its maximum torque beginning at about 2500 RPM.
2. Which of the following can occur if a technician does not follow proper procedures when working on the systems discussed in this chapter?
   A. Fatal shock
   B. Arc flash
   C. Arc blast
   D. All of the above
3. Technician A says that the information contained in this chapter is not sufficient to allow readers to work on the high-voltage systems discussed. Technician B says that the information contained in this chapter is for informational purposes only and that a technician should only work on the high-voltage systems discussed in this chapter after completing the appropriate manufacturer training. Who is correct?
   A. Technician A only
   B. Technician B only
   C. Both technicians
   D. Neither technician
4. How many cylindrically shaped batteries (cells) are used in the Insight, the Civic Hybrid, and the Accord Hybrid to form the HV battery?
   A. 1
   B. 3
   C. 120
   D. 168
5. On the Honda IMA system, which of the following is the primary power source to power the drive wheels?
   A. EMG
   B. CVT
   C. PCU
   D. Gasoline engine
6. Which of the following gasoline engines is used in the Honda Insight?
   A. 1.0-L VTEC
   B. 1.3-L i-DSI
   C. INZ-FXE 1.5-L
   D. 3.0-L i-VTEC
7. The Honda Civic Hybrid qualifies as which of the following?
   A. ULEV
   B. SULEV
   C. ZEV
   D. AT-PZEV
8. On the Honda Civic Hybrid, how does the VCM system deactivate a cylinder?
   A. It only disables the fuel injector and allows the valves to continue to operate.
   B. It only disables the ability of the valves to open and allows the fuel injector to continue to operate.
   C. It disables the fuel injector and also disables the ability of the valves to open.
   D. It only disables the ignition system's spark to the cylinder.
9. Which of the following is used in the Honda Accord Hybrid to lessen the awareness of the driver to the deactivation of cylinders by the VCM system?
   A. An active control engine mount
   B. An "Active Noise Control" system
   C. A 4-inch-thick firewall
   D. Both A and B
10. Technician A says that the EPA fuel economy rating on a Toyota Prius is greater for city driving than for highway driving. Technician B says that a Toyota Prius uses a throttle cable to allow the throttle pedal to physically control the throttle body on the gasoline engine. Who is correct?
    A. Technician A only
    B. Technician B only
    C. Both technicians
    D. Neither technician
11. What is the name of the electric motor/generator that drives the front-drive wheels on a Toyota Prius?
    A. MG1
    B. MG2
    C. MGF
    D. MGR
12. What is the primary purpose of the coolant heat storage capability on the Toyota Prius?
    A. To reduce vehicle emissions following a cold engine start

B. To bring the climate control system up to operating temperature more quickly following a cold engine start
C. To provide extra heat to the HV battery following a cold start
D. To provide extra heat to MG2 as the vehicle is initially accelerated following a cold engine start

13. Technician A says that on the THS-II system as it is used on the Toyota Prius, the voltage that is applied to MG1 or MG2 is 201.6 V. Technician B says that on a Toyota Prius equipped with the “Smart Key” system, the driver can enter the vehicle while locked and drive it away without having to physically put the key into the door’s lock cylinder or the ignition switch. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

14. On the 2006 Toyota Highlander Hybrid, what is the voltage output of the boost converter/inverter?
A. 201.6 V AC
B. 273.6 V AC
C. 500 V AC
D. 650 V AC

15. In the event of a vehicle accident, which of the following on the Ford Escape Hybrid is used to cause the battery control module to open the high-voltage circuit by electrically dividing the HV battery in half?
A. A single inertia switch located in the front of the vehicle only
B. A single inertia switch located in the rear of the vehicle only
C. Either of two inertia switches, one located at the front of the vehicle and one located at the rear of the vehicle
D. The loss of the tach reference signal form the gasoline engine’s ignition system to the PCM

16. Technician A says that on the Ford Escape Hybrid, refrigerated air from the climate control system is used to cool the HV battery when the A/C system is activated. Technician B says that on the Ford Escape Hybrid, it is likely that the rear brakes will wear out before the front ones do. Who is correct?
A. Technician A only
B. Technician B only
C. Both technicians
D. Neither technician

17. The Honda FCX emits which of the following emissions?
A. CO_2 only
B. NO_x only
C. CO_2 and NO_x
D. Heat and water

18. Which of the following technologies is being used on the Nissan Altima beginning with the 2006 model year?
A. Honda hybrid technology
B. Toyota hybrid technology
C. Ford hybrid technology
D. Fuel cell technology

19. Which of the following manufacturers’ hybrid-drive vehicles uses the gasoline engine as the primary power source and uses an electric motor/generator to assist it only when the load requires?
A. Honda
B. Toyota
C. Nissan
D. Ford

20. Which of the following hybrid vehicles uses a control module strategy called Grade Logic Control to reduce the driver’s need for constantly having to compensate at the throttle pedal for transmission upshifts and downshifts when driving in mountainous terrain?
A. Honda Accord
B. Toyota Prius
C. Toyota Highlander
D. Ford Escape

Appendix A

Approach to Diagnostics

Now that you have read this book, you might be wondering how best to apply the information when a vehicle is brought into your service bay for diagnosis and repair. Sometimes it can be difficult to put theory into action. This appendix is designed to help the reader understand how to convert the information contained in this book into hands-on diagnostics.

NARROWING DOWN THE AREA OF THE PROBLEM

If someone asked you to guess a number between 0 and 1000 in a minimal number of guesses, but with the promise that he/she would also inform you as to whether each guess was too high or too low, you would do well to begin guessing with the number 500. This cuts the possibilities in half. And if their next response was that your number was too high, your next best guess would be 250, cutting the possibilities in half again. So it is with diagnosing complex automotive electronic systems.

Your initial goal in diagnosing a fault of any type (hard fault or soft fault) should be to narrow down the problem area associated with the symptom to as small an area as possible. You may take several approaches to accomplish this. Failure to reduce the possibilities can result in extreme frustration, as most technicians have experienced at one time or another.

Use the following tips to help you narrow down the area of the problem before you begin pinpoint testing. You can thereby minimize your frustration and increase your diagnostic effectiveness in spite of the complexity of modern automotive systems.

Talking to the Customer

First, when the vehicle is brought into your shop, gather information from the customer and record it on the repair order. Include as much information as possible about the conditions under which the symptom appears. It is also important to find out if the vehicle has been taken to a shop for the same symptom prior to this service. If you listen carefully, what the customer states about the problem may provide clues to the type of problem the vehicle has, such as “This problem has been happening *ever since. . . .* That “ever since” might be just the clue you need.

You might also ask the customer to show you the problem as he/she is experiencing it. For example, this author once received a repair order identifying the symptom as “headlights will not stay turned on” on a vehicle that had been purchased new three days earlier. When I was unable to verify the symptom, I asked the customer, who was in the waiting room, to come back to my service bay and show me the problem she was experiencing. She literally reached through the open driver’s door window, pulled back on the "flash-to-pass" switch, and said, "See, when I let go, the headlights turn off." I then explained to her that, though this new vehicle was new technology in her eyes, it still had a traditional push/pull headlight switch in the dash.

Unfortunately, in many shops, the technician is not encouraged to speak directly with the customer except as a last resort.

Symptom Verification

The first real step in diagnosis is to attempt to verify the *exact* symptom. If the symptom can be verified, you are likely dealing with a hard fault. If the symptom cannot be verified, you are likely dealing with a soft fault. Hard faults should always be diagnosed before attempting to diagnose any soft faults. While there are some differences between diagnosing a hard fault and a soft fault, most of the following information applies to diagnosing faults of either type.

With your understanding of how the system is designed to operate, symptom verification can help you narrow down the area in which you need to perform pinpoint tests. In fact, what you are really doing is mentally creating a flowchart. For example, if the customer complains that there seems to be a short in the exterior lighting circuits because other circuits seem to energize the running lights (park, tail, and side marker lights), the first step would be to gain an understanding of how the system is designed to operate. If it is an unfamiliar system, this can be done through the electrical schematics associated with the system. (Ever notice how most flowcharts also include electrical schematics?) The next step would be to verify the *exact* symptom. This can be accomplished by operating each of the exterior lighting systems and noting the results. For example, if the exterior running lights illuminate when the left directional signal is activated but not with the right directional, it is likely that the short is located on the left side of the vehicle. If the exterior running lights illuminate when the brake pedal is depressed, the short is at the rear of the vehicle. Thus, verification of the exact symptom can be used to narrow down the problem area, in this case to the left rear corner of the vehicle. Next perform a visual check at that corner of the vehicle, beginning with the bulbs—you may find a dual-filament bulb that has a filament that has broken loose and is physically touching the other filament. Because you narrowed the problem down to one corner of the vehicle by using the *exact verified symptoms,* you do not have to perform visual checks and pinpoint tests at all four corners of the vehicle—only at the one corner identified by the symptoms. This type of approach ultimately results in less frustration in that it is easier to perform pin-point tests of a particular area as opposed to tearing apart harnesses and components throughout the entire vehicle.

Visual Inspection

A thorough visual inspection of the system(s) associated with the symptom should be performed. If this is done properly and conscientiously, problems can often be identified at this time. Additional visual inspections may need to be performed as the area of the fault is further narrowed down through diagnostic processes such as code pulling and gas analysis.

Assistance from the Onboard Computers

An important aid to help the technician narrow down the problem area is to take advantage of the abilities of onboard computers; they are programmed to offer you their assistance.

Diagnostic Trouble Codes. Modern onboard computers are programmed, at the very least, to allow the technician to pull memory diagnostic trouble codes (DTCs). Others will allow the technician to perform a self-test of the system. Both memory codes and self-test codes can quickly identify a problem area or circuit for the technician. But if a DTC is set as the result of an electrical open in a specific circuit, the technician must still perform pinpoint tests to identify the exact location and cause of the open.

Data Stream. All OBD II systems and most pre–OBD II systems allow the technician to look at data stream PIDs and related information concerning sensor values and actuator commands. This is extremely effective in helping the technician to narrow down the problem to a specific area or circuit. But suppose, for example, the data stream information identifies an NTC thermistor circuit as reporting a temperature of −40°F; while the technician now knows that there is an open in the specific circuit, further pinpoint tests must be performed to identify the exact location and cause of the open.

Other Scan Tool Functions. Most computers will also perform other functional tests, either using manual methods to trigger these functions or with the help of a scan tool. For example, the technician may be able to use a scan tool to command the computer to energize a specific actuator (active command or bidirectional control). This helps the technician to quickly narrow down a problem associated with that system to either the input side or the output side of the computer. If an actuator that does not operate normally now operates under the scan tool's direction, we know that the computer can successfully energize the actuator, thus eliminating the output side of the computer as a possible fault; the technician would check the sensors, switches, and other inputs next. But if the actuator will not operate when the scan tool commands it to, the actuator and its related wiring/connectors should be checked.

Other functional tests may also be available, depending upon the scan tool and the vehicle itself. For example, on some systems a scan tool can command the PCM to conduct a cylinder power balance test (this may be built into the PCM's program or the scan tool's program).

PCM's versus Other Control Modules. These scan tool diagnostic features are not limited to engine control systems; they also apply to other electronic systems on today's vehicles. For example, a scan tool may also be used to pull memory codes, initiate a self-test, or look at data stream information on many antilock brake systems, body control systems, instrument clusters, and so on. Certain non-engine systems, particularly on older vehicles, may allow the technician to manually trigger memory code pulling or self-tests, such as a test of the Electronic Automatic Temperature Control (EATC) system, by pushing various combinations of buttons on the climate control head. If the computer is programmed to help you, take advantage of it.

Also, many modern scan tools offer a mode that checks all onboard computers for any fault codes with a single scan tool request, thus allowing the technician to determine very easily any fault codes associated with any computer on the vehicle without having to select each computer individually in the scan tool's menu.

Exhaust Gas Analyzer

A third approach to narrowing down the problem area when diagnosing an engine system for poor performance, poor fuel mileage, or failed emission tests is to use an exhaust gas analyzer to capture exhaust readings at both idle and 2500 RPM, and then to use these readings to give you an idea of the type of problem that you are attempting to diagnose. For example, a high CO reading would indicate that you should look for problems that could result in a rich air/fuel ratio—either too little air or too much fuel. As a result, analyzing the exhaust gasses of an engine can help a technician quickly narrow down the problem area, although it cannot identify the exact problem. An exhaust gas analyzer becomes an invaluable tool when attempting to minimize the frustration factor.

When using an exhaust gas analyzer as a diagnostic tool, use the gasses to determine the actual air/fuel ratio and Lambda values (see Chapter 16 for an explanation of Lambda). Newer exhaust gas analyzers perform this calculation for you from the measured gasses. If you are using an older analyzer that does not perform this task, use an automated "air/fuel ratio and Lambda" calculator that is available on the Internet such as the one found at the International Automotive Technicians' Network (IATN) (http://www.iatn .net). Simply enter your four or five measured gasses (with or without the NO_x value) in the automated calculator to calculate the air/fuel ratio and Lambda values. It is very helpful to know what these values are when attempting to narrow down the problem area. This will also serve as an early indicator as to whether or not the PCM is in proper control of the air/fuel ratio.

Verifying PCM Control of the Air/Fuel Ratio

When diagnosing a complaint of poor engine performance, poor fuel economy, or an emissions test failure, you will need to verify the ability of the PCM to properly control the air/fuel ratio. This can be done through the primary oxygen sensor's voltage waveform, but only if the oxygen sensor itself has first been tested and proved to be in good condition.

Testing the Oxygen Sensor. To verify the oxygen sensor, use a DSO to monitor the oxygen sensor's waveform while forcing the air/fuel ratio both rich and lean. This can be done on most vehicles by simply throttling the engine in the service bay. On a fuel-injected engine, suddenly opening the throttle (acceleration) results in a rich air/fuel mixture, and allowing the throttle to close (deceleration) results in a lean air/fuel mixture. If needed, a propane enrichment tool can be used to force the mixture rich. Then suddenly turning off the propane will force the mixture lean.

A zirconia-type oxygen sensor should be capable of exceeding 800 mV while the air/fuel ratio is rich, then descending to less than 175 mV when the air/fuel ratio is lean. It should be able to switch between 300 mV and 600 mV in either direction in less than 100 ms. It should never show a negative value. Any failure in any of these areas is cause for replacement. If you replace the oxygen sensor, drive the vehicle about 10 miles to break in the new oxygen sensor before you attempt to test it.

Testing the PCM's Ability to Control the Air/Fuel Ratio. Once the oxygen sensor has been verified, sample the oxygen sensor waveform with a DSO while driving the vehicle on a road test. Be sure to have another technician drive the vehicle so that you can safely monitor the DSO. (A scan tool with a data-graphing capability may also be used.) The oxygen sensor should show a consistent cross-counting of its voltage to both sides of the stoichiometric value. Additionally, fuel trim values should be monitored with a scan tool during the road test. The short-term fuel trim should be reacting to the oxygen sensor's voltage. If the vehicle has electronic fuel injection (either TBI or PFI), the oxygen sensor's voltage should indicate a lean condition during vehicle deceleration. All of this indicates that the PCM is in proper control of the air/fuel ratio. If the oxygen sensor's voltage indicates that the air/fuel ratio is pegged either rich or lean, or is averaging outside of the 400- to 500-mV range (zirconia-type O_2 sensor), the PCM is not in proper control of the air/fuel ratio and the following steps should be taken to narrow down the area of the problem to the *electronics* or to something *mechanical*.

Narrowing Down the Problem Area to an Electronic Fault or a Mechanical Fault. If the oxygen sensor's voltage is pegged either rich or lean, compare this signal with the pulse-width command to the fuel injectors. If the oxygen sensor's voltage is pegged lean and the pulse-width command indicates that the PCM is attempting to enrich the air/fuel ratio, we can rule out the electronics (sensors and computer) as being responsible for the fault—the problem is mechanical and is outside of the computer's ability to control it. Likewise, if the oxygen sensor voltage is pegged rich and the pulse-width command indicates that the PCM is attempting to lean out the air/fuel ratio, we can again rule out the electronics as being responsible for the fault—again, the problem is mechanical. When the fault is identified as mechanical, look for the following types of problems:

- vacuum leaks
- plugged or leaking fuel injectors
- plugged fuel filter
- ruptured fuel pressure regulator diaphragm (return-type system)

- false air upstream of the oxygen sensor from either an exhaust leak or a faulty secondary air-injection system

If the pulse-width command to the fuel injectors indicates that the PCM is not reacting properly to the oxygen sensor signal (and is in fact responsible for the pegged rich or lean condition), then the problem is electronic. When the fault is identified as electronic, test the following areas:

- sensors and other input circuits
- 5-V reference voltage to the sensor (TPS, for example)—indicative of the voltage that is also applied to the computer's internal logic gates
- excessive resistance in the PCM's power or ground circuits (voltage drop should not exceed 100 mV total in either the power side or in the ground side)
- If all above tests are okay, replace the PCM itself.

Using a scan tool to look at fuel trim values in comparison to the oxygen sensor value is also an excellent tool for determining if the fault is electronic or mechanical. However, when using fuel trim values, verify that the PCM is operating in the correct fuel trim cell for the current operating condition. If an engine load sensor (MAP or MAF sensor) is reporting that the engine is under more load than it really is, the PCM will use an incorrect fuel trim cell in an upper load area; as a result, the PCM will be locked into a window of longer fuel injector pulse widths. If you simply note the fuel trim values without noting the fuel trim cell number, these values will indicate that the PCM is attempting to subtract fuel—and yet the total pulse width will be too long for the condition. If in doubt, back up your fuel trim values by reading actual PCM-commanded injector on-time, either with a scan tool or with a DSO/DVOM. A helpful tool in this area is a scan tool that shows the values of all fuel trim cells, such as the PC-based scan tool from Automotive Test Solutions (http://www.automotivetestsolutions.com).

PINPOINT TESTING

To isolate any remaining hard faults, visualize the electrical circuit in three parts: the source (battery or alternator), the circuitry, and the load component. The source is the first component that should be verified. For example, if the starter cranks slowly, check the battery's open-circuit voltage and then load test it. It is a good idea to test the battery's open-circuit voltage for symptoms associated with smaller load components, even if the starter cranks normally, due to the effects of low open-circuit voltage on computer operation. Also, do not overlook the effects of excessive alternator ripple on computer-controlled systems. To test this, connect a DVOM between the alternator positive and negative terminals while scaled to an AC voltage scale. With the engine running, AC voltage should stay well below 500 mV, preferably less than 300 mV. Excessive alternator ripple can, of course, also be seen with a DSO (lab scope).

To test the circuitry, use a DVOM on a DC voltage scale to perform voltage-drop tests on both the positive and negative sides of the circuit (see the section about voltage-drop testing in Chapter 6). This verifies the integrity of the circuitry used to connect the source to the load component. While 100 mV per connection is allowed in normal circuits (and even 200 mV per connection in starter circuits due to the high-current, low-resistance designs of these circuits), a power or ground circuit that is used to power up a PCM (or other computer) should never exceed 100 mV *total* voltage drop in either the positive circuit or in the negative circuit with the key on, engine off (KOEO). This tight specification is due to the high-resistance, low-current flow designs of these circuits. Many good PCMs are replaced simply because of a poor power or ground circuit. Therefore, after verifying each of the input and output circuits, but before replacing the PCM, you should get in the habit of using an electrical schematic to identify each of the PCM's power and ground terminals. Then with the ignition on, perform voltage-drop tests between the battery and the PCM.

Ultimately, the load component can be tested by the following methods. If the load component is an electronic control module, simple elimination of possible faults elsewhere in the circuitry through voltage-drop testing is used most often to narrow down the problem to the control module itself. Other load components can be tested electrically and functionally. Electrical tests involve the use of an ohmmeter to measure a solenoid's (or relay's) resistance in the windings, or jumper wires to energize the component. Functional testing can be done using other methods, depending upon the type of actuator being tested. For example, use a vacuum pump opposite a vacuum gauge to test a vacuum solenoid.

Other tools that can make pinpoint testing easier include DSOs, logic probes, and breakout boxes (see Chapter 6). DSOs can show voltage waveforms, logic probes can quickly check for the presence of ignition primary, and fuel injector signals and breakout boxes can be used to improve computer circuit accessibility without backprobing.

Finally, flowcharts and electrical schematics are invaluable when it comes to pinpoint testing. A flowchart is written according to the design engineer's understanding of system operation. An electrical schematic helps you as a technician to understand system operation.

Technical Service Bulletins

The next step that should be performed is checking the manufacturer-issued Technical Service Bulletins (TSBs). These are usually available either through electronic information systems or directly from the manufacturer. A TSB is a manufacturer-suggested repair for a problem the manufacturer is already aware of. It may involve a simple fix or it may involve something as in-depth as replacing a PCM or a PROM chip in the PCM, or even reflashing of the PCM. Make sure that you use the latest TSB issued for the particular symptom that you are trying to diagnose and repair, as multiple TSBs have sometimes been issued in attempting to correct a single problem. Ultimately, access to TSBs is critical to a technician attempting to diagnose engine performance problems and can lead to increased diagnostic effectiveness.

Do Not Overlook the Basics

When warranted, the basic engine systems—compression, ignition, and air/fuel delivery—must not be forgotten. A vacuum gauge can be used to quickly give the technician ideas about possible fault areas that should be tested further. A cylinder power balance test (performed either with an ignition scope, through a functional test programmed into the PCM [as on Ford EEC-IV systems], or with a scan tool [many modern scan tools]) can quickly identify cylinders that may be lacking compression, spark, or fuel delivery. If one or more cylinders are identified as being weak, the following areas should be looked at.

Compression. Performing a compression test on each of the cylinders while the starter is cranking the engine and the throttle is held open (known as a *cranking compression test*) tests for cylinder seal. For example, a burned valve could easily cause a particular cylinder to fail this test due to the leak it creates.

However, if all cylinders pass this test and spark and fuel are verified with an exhaust gas analyzer, a running compression test should be performed. To perform this test, all spark plugs must be reinstalled except the one in which the compression gauge is connected. Then the engine is started. Once the engine is running, momentarily release the compression gauge pressure. Now note the compression pressure at idle, at 1500 RPM, and on a snap throttle. At idle and 1500 RPM, the pressure reading will be about one-half of the cranking compression due to the closed throttle and the faster piston speed. Because of the faster piston speed, this is a very poor test to check cylinder seal, but it is an excellent test to check and compare each cylinder's volumetric efficiency (the cylinder's ability to breathe in and out). It is difficult to apply a hard specification to this test because of different camshaft grinds; instead, the cylinders should simply be compared. One or two cylinders showing lower readings than the rest indicates an inability to *breathe in* because of an improper opening of the intake valve, and one or two cylinders showing higher readings than the rest indicates an inability to *breathe out* because of an improper opening of the exhaust valve. This inability of the engine to breathe properly is caused by problems in the valve train such as loose rocker arms, worn push rods/lifters, or a worn cam lobe. Because these valves still seal when closed, the cranking compression test does not identify the problem. One point to note: Have some spare Schrader valves on hand for your compression gauge when performing running compression tests.

Ignition. If the engine cranks but does not start, both secondary ignition and primary ignition should be checked. If the tach reference signal is not present, either from a distributor or from a crankshaft sensor, neither secondary spark nor fuel injection pulses will be present. If there is a spark being produced in an ignition coil or if the fuel injectors are being pulsed, the distributor pick-up/crankshaft sensor is functioning.

If the engine starts and runs but has performance problems or misfire present, the secondary ignition waveform should be checked on an ignition oscilloscope. And if a shorted primary coil winding is a possibility, use a DSO coupled with a current probe to test each primary coil winding through its current waveform.

Air/Fuel. This area includes the common maintenance items such as air and fuel filters and the PCV valve and crankcase ventilation filter. Also, if the engine has failed a cylinder power balance test, measure the exhaust emissions with an exhaust gas analyzer at both idle and 1500 RPM. Then turn off the engine and disable the spark for the failed cylinder. On distributor and waste spark systems, simply use a jumper wire to short one spark plug wire to or from engine ground. On coil-on-plug (COP) systems, simply disconnect the primary connector from the coil for the failed cylinder. Now restart the engine. If burned hydrocarbons increase dramatically from their previous values, the failed cylinder has both spark and (at least some) fuel present. If this is the case, then cranking and running compression tests should be performed (if they have not already been performed).

Another concern is the quality of the fuel. If excessive alcohol in the fuel is a possibility, mix a sample of the vehicle's fuel with some water in a graduated cylinder. The gasoline will float above the water, creating a gasoline/water line between them. Shake the cylinder vigorously for 30 seconds and then let it settle. After settling, if the height of the gasoline/water line is increased, it is because of alcohol content in the gasoline sample—the alcohol separates from the gasoline and combines with the water during this test. Use the increase in the height of the gasoline/water line to calculate the percentage of alcohol content. Except for E85 fuel (when working on an E85-capable vehicle), any alcohol content in excess of 10 percent can create fuel volatility problems.

Finally, a fuel test kit can be used to measure the specific gravity of a sample of the vehicle's gasoline (similar to specific gravity tests of a lead acid battery's electrolyte when the cell caps were removable). Although it does not directly measure the fuel's Reid Vapor Pressure (RVP), the fuel's specific gravity will be indicative of the fuel's volatility. (RVP measures a fuel's volatility by measuring how much pressure the fuel will create in a confined space when heated to 100°F, at which pressure the fuel quits boiling/vaporizing.) The specific gravity of the fuel should also quickly alert you to any diesel fuel that might have been put into a gasoline engine's fuel tank inadvertently.

Flowcharts

Flowcharts are designed to aid the technician in making appropriate pinpoint tests that are applicable to the DTC or symptom. When using them, be sure to perform the following:

- Read and follow the test instructions carefully.
- Do not skip any test steps and assume their outcome—this can result in misdiagnosis and/or wasted time.
- Be sure of your equipment—does your DVOM or DSO read battery voltage when the leads are placed across the battery? Or does your jumper wire have continuity?
- Make the repair as indicated in the final step—you can be confident of what it is asking you to do if you have carefully followed all test steps and not skipped any.

Reducing Your Dependence on Flowcharts

While they are a necessary diagnostic tool, flowcharts may be restrictive for the following reasons:

- Their content is limited to the engineer's ability to imagine all potential problems that could develop with the system.
- They will occasionally contain an error.
- They are time consuming—it can take you longer to read and understand what the flowchart is asking you to test than the flat rate for the job pays.
- If someone has altered the OEM design in the aftermarket, the flowchart may no longer apply.

Another approach that will reduce your dependence on flowcharts is to diagnose the system through your own understanding of how the system is designed to operate. The following is required for a technician to understand the operation of an unfamiliar system:

- a working knowledge of electrical laws
- a working knowledge of electronics—inputs, processing, and outputs
- the ability to read and interpret an electrical schematic

Interpreting an Electrical Schematic. Following are a few ideas that will help you interpret a complex electrical schematic. It helps to begin by copying or printing out the electrical schematic so that you can draw on it.

- *First: Identify the components.* Highlight the components with a yellow highlighter if necessary. This quickly simplifies a seemingly complex schematic. It also keeps you from inadvertently attempting to interpret the outline of a module as a circuit.
- *Second: Identify the powers and grounds.* You might use red or orange for power and green for grounds.
- *Third: Identify the input and output circuits.* You might use blue for inputs and purple for outputs. Bear in mind that sometimes an ignition-switched voltage operates as an input to a control module, as with an illuminated entry system. In this system, battery voltage is used to power up the module. The ignition voltage only acts as an input to let the module know that it may turn off the interior lights.
- *Fourth: Identify any data busses used for communication between computers.*

Other Diagnostic Resources

In most difficult diagnostic situations, the odds are that someone else, somewhere else, has already encountered and solved the problem that you are striving to solve. Following are some examples of these resources.

International Automotive Technicians' Network. The International Automotive Technicians' Network (IATN) can be a valuable resource in helping the technician solve difficult problems. Accessible at http://www.iatn.net, this Web site offers many valuable tools, from technician interaction to manufacturer-provided information and other technical resources. IATN offers both a free membership and a sponsoring membership.

Identifix. An updated version of IATN, Identifix offers an online diagnostic information service designed to aid the automotive service technician in diagnosing difficult problems. Accessible at http://www.identifix.com, this Web site is administered by Automotive Information Systems (AIS), Inc. (founded in 1987). They employ 30-plus factory-certified ASE master technicians. Unlike IATN, Identifix technicians work to verify information from other technicians before posting it to their Web site.

World Wide Web. Finally, the World Wide Web (www) can sometimes be helpful in solving a difficult problem. Simply perform a "Google" search for a specific symptom on a specific make, model, and year of vehicle and you may find a helpful repair hint.

ADDITIONAL INFORMATION CONCERNING SOFT FAULT DIAGNOSIS

This question is often asked: How can I pinpoint test a fault when the symptom does not appear to be present? There are several answers to this question. Certainly, past experience on like models with similar problems counts for something. Unfortunately, this approach often results in improper repairs and unnecessary parts replacement. A better approach is suggested in the following paragraphs.

The first step is to determine whether the PCM has stored any DTCs in memory that could direct you to a probable problem area. At the very least, a memory DTC can help you determine if the reason for an "intermittent engine shutdown until cooled" is the likely result of the ignition system or the fuel system. However, additional tests can be performed to pinpoint test the exact cause, even when the symptom does not appear to be present.

If the soft fault is in the circuitry, performing voltage-drop tests of the circuitry will locate the fault, even when the circuit appears to be functioning normally. Remember, voltage-drop testing is used to identify excessive unwanted resistance in the circuitry. This excessive unwanted resistance increases with an increase in temperature to the point of creating a symptom. Likewise, this resistance decreases with a decrease in temperature, to the point that the circuit again becomes operational. The excessive unwanted resistance does not totally disappear, even when the circuit appears operational and the symptom does not appear to be present. Thus, if a soft fault is in the circuitry, voltage-drop testing can identify the circuit problem even without the symptom present. While the voltage-drop reading will not be as excessive as when the symptom is present, it will still likely be above acceptable limits.

If the soft fault is in the load component, using a DSO (lab scope) and a low-current probe to sample the current waveform of the load component can identify faults in the load component that can cause intermittent operation (see Chapter 6). This is particularly true of motors. The current waveform can identify an open or shorted winding within the motor as well as some other faults that will weaken the motor's strength and result in intermittent symptoms associated with the motor. In this way, a load component can be proved to be defective, even though it may still be operational while in your shop. This technology allows you to show your customer a printed waveform that proves that a load component is not being replaced needlessly. It can even allow you to identify a load component that is ready to fail, even before symptoms have been encountered.

SUMMARY

This appendix is designed to help the reader put some of the information contained in various chapters of this book into perspective. No one chapter is going to provide a quick repair guide to all the problems encountered on today's complex vehicles. Rather, it takes an understanding of the concepts covered in the first chapters, in combination with the product-specific information covered in the later chapters, to effectively diagnose and repair today's modern systems. Even then, in spite of this author's best efforts, none of us will ever fully retain all of the system and product-specific information necessary for effective repair and diagnosis. Therefore, a source of product-specific information is as necessary as any other tool that you might use in your business. These service manuals may be paper or electronic, but they are very necessary.

A good technician today cannot know it all. Rather, he/she must strive to understand the operating and diagnostic concepts associated with today's modern systems and then know where to look up the product-specific information when an unfamiliar system is encountered. If this textbook has provided the reader with an understanding of the underlying concepts and with the knowledge required to comprehend the paper/electronic service manual literature, then our goal has been achieved.

Appendix B

Terms and Acronyms

This appendix contains figures that provide terminology and acronyms for common (non–manufacturer-specific) terms, OBD II terms, and terms for both domestic and Asian vehicles, as well as many of their OBD II counterparts as applicable. The figures list the manufacturers' terms and acronyms in the same order that these manufacturers are addressed through the chapters of this book.

Term	Acronym	Term	Acronym
Air Conditioning	A/C	Ohms	Ω
Alternating Current	AC	Oxides of Nitrogen	NO_x
Amps	A	Oxygen	O_2
Analog Volt/Ohm Meter	AVOM	Park/Neutral	P/N
Carbon Dioxide	CO_2	Ported Vacuum Switch	PVS
Carbon Monoxide	CO	Positive Crankcase Ventilation	PCV
Digital Volt Meter	DVM	Programmable Read-Only Memory	PROM
Digital Volt Ohmmeter	DVOM	Pulse-Width Modulated	PWM
Direct Current	DC	Random-Access Memory	RAM
Hydrocarbons	HC	Read-Only Memory	ROM
Ignition	IGN	Revolutions per Minute	RPM
Instrument Panel	IP or I/P	Tachometer	TACH
Key On, Engine Crank	KOEC	Thermal Vacuum Switch	TVS
Key On, Engine Off	KOEO	Thermostatic Air Cleaner	TAC
Key On, Engine Running	KOER	Variable Pulse Width	VPW
Miles per Hour	MPH	Vehicle Identification Number	VIN
Nitrogen	N_2	Volts	V
Normally Closed	N/C	Water	H_2O
Normally Open	N/O	Wide-Open Throttle	WOT

Figure B–1 Common terms and acronyms.

OBD II Term	OBD II Acronym
Air-Conditioning Clutch	ACC
Air-Conditioning Cycling Switch	ACCS
Air-Conditioning Demand	ACD
Barometric Pressure sensor	BARO sensor
Camshaft Position sensor	CMP sensor
Canister Purge	CANP
Crankshaft Position sensor	CKP sensor
Data Link Connector	DLC
Diagnostic Link Connector	DLC
Diagnostic Trouble Code	DTC
Distributor Ignition*	DI
Early Fuel Evaporation	EFE
Electronic Ignition**	EI
Engine Coolant Temperature sensor	ECT sensor
Evaporative Emission Control System	EVAP
Flexible Fuel	FF
Generator (Alternator)	GEN
Heated Oxygen Sensor	HO_2S
Idle Air Control	IAC
Idle Speed Control	ISC
Intake Air Temperature sensor	IAT sensor
Knock Sensor	KS
Long-Term Fuel Trim	LTFT
Malfunction Indicator Lamp	MIL
Malfunction Indicator Light	MIL
Manifold Absolute Pressure sensor	MAP sensor
Mass Air Flow sensor	MAF sensor
Mixture Control solenoid	MC solenoid
Multiport Fuel Injection	MFI
Oxidation Catalyst	OC
Oxygen Sensor	O_2S
Power Steering Pressure	PSP
Powertrain Control Module	PCM
Pulsed Secondary Air Injection Reaction system	PAIR system
Secondary Air Injection Reaction system	AIR system
Sequential Fuel Injection	SFI
Short-Term Fuel Trim	STFT
Speed Density	SD
Three-Way Catalyst	TWC
Throttle Body Injection	TBI
Throttle Position Sensor	TP sensor or TPS
Torque Converter Clutch	TCC
Transmission Control Module	TCM
Vehicle Speed Sensor	VSS

**Mechanical spark distribution using a single coil and a distributor.*
***Electronic spark distribution using multiple coils and no distributor.*

Figure B–2 OBD II standardized terms and acronyms.

GM Term	GM Acronym	OBD II Acronym
Air Injection Reaction	AIR	AIR
Assembly Line Communication Link	ALCL	DLC
Assembly Line Diagnostic Link	ALDL	DLC
Backpressure EGR	BPEGR	BPEGR
Barometric Pressure sensor	BARO sensor	BARO sensor
Block Learn		LTFT
Charcoal Canister Purge	CCP	CANP
Check Engine Light	CEL	MIL
Climate Control Panel	CCP	
Computer Command Control	CCC or C3	
Computer-Controlled Coil Ignition	C3I	
Coolant Temperature Sensor	CTS	ECT sensor
Digital Fuel Injection	DFI	
Direct Ignition System	DIS	
Early Fuel Evaporation	EFE	EFE
Electronic Climate Control	ECC	
Electronic Climate Control Panel	ECCP	
Electronic Control Module	ECM	PCM
Electronic Fuel Injection	EFI	
Electronic Spark Control	ESC	
Electronic Spark Timing	EST	
Evaporative Emission Control System	EECS	EVAP
Exhaust Gas Recirculation	EGR	EGR
Fuel Data Panel	FDP	
Heated Oxygen Sensor	HO_2S	HO_2S
High Energy Ignition	HEI	
Idle Air Control	IAC	IAC
Idle Load Compensator	ILC	
Idle Speed Control	ISC	ISC
Integrated Direct Ignition	IDI	
Integrator		STFT
Manifold Absolute Pressure sensor	MAP sensor	MAP sensor
Manifold Air Temperature sensor	MAT sensor	IAT sensor
Mass Air Flow sensor	MAF sensor	MAF sensor
Mixture Control solenoid	M/C solenoid	MC solenoid
Multiport Fuel Injection	MFI	MFI
Oxygen Sensor	O_2S	O_2S
Port Fuel Injection	PFI	MFI
Power Steering Switch	PSSw	PSP
Pulse Air Injection Reaction	PAIR	PAIR
Sequential Fuel Injection	SFI	SFI
Throttle Body Injection	TBI	TBI
Throttle Position Sensor	TPS	TP sensor or TPS
Torque Converter Clutch	TCC	TCC
Tuned Port Injection	TPI	
Vehicle Control Module	VCM	
Vehicle Speed Sensor	VSS	VSS

Figure B–3 General Motors terms and acronyms.

Ford Term	Ford Acronym	OBD II Acronym
Adaptive Strategy		LTFT/STFT
Air Charge Temperature sensor	ACT sensor	IAT sensor
Air-Conditioning Clutch	ACC	
Air-Conditioning Cycling Switch	ACCS	
Air-Conditioning Demand	ACD	
Backpressure EGR	BPEGR	BPEGR
Barometric Pressure sensor	BP sensor	BARO sensor
Brake On/Off switch	BOO switch	
Canister Purge	CANP	CANP
Central Fuel Injection	CFI	TBI
Clutch Engaged Switch	CES	
Computer-Controlled Dwell	CCD	
Crankshaft Position sensor	CP sensor	CKP sensor
Cylinder Identification	CID	
Delta Pressure Feedback EGR sensor	DPFE sensor	
Differential Pressure Feedback EGR sensor	DPFE sensor	
Distributorless Ignition System	DIS	
Dual Plug Inhibit	DPI	
EGR Control solenoid	EGRC solenoid	
EGR Valve Position sensor	EVP sensor	
EGR Valve Regulator solenoid	EVR solenoid	
EGR Vent solenoid	EGRV solenoid	
Electronic Control Assembly	ECA	PCM
Electronic Distributorless Ignition System	EDIS	
Electronic Engine Control	EEC I, II, III, IV, V	
Electronic Fuel Injection	EFI	MFI
Engine Coolant Temperature sensor	ECT sensor	ECT sensor
Exhaust Gas Oxygen sensor	EGO sensor	O_2S
Exhaust Gas Recirculation	EGR	EGR
Failure Mode Effects Management	FMEM	
Feedback Carburetor Actuator	FBCA	
Fuel Pump Monitor	FPM	
Heated Exhaust Gas Oxygen sensor	HEGO sensor	HO_2S
Idle Speed Control	ISC	ISC
Idle Tracking Switch	ITS	
Ignition Diagnostic Monitor	IDM	
Inferred Mileage Sensor	IMS	
Inlet Air Solenoid	IAS	
Integrated Relay Control Module	IRCM	
Integrated Vehicle Speed Control	IVSC	
Keep-Alive Memory	KAM	
Keep-Alive Power	KAPWR	
Key On, Engine Off	KOEO	
Key On, Engine Running	KOER	
Knock Sensor	KS	KS

Ford Term	Ford Acronym	OBD II Acronym
Limited Operational Strategy	LOS	
Malfunction Indicator Lamp	MIL	MIL
Manifold Absolute Pressure sensor	MAP sensor	MAP sensor
Mass Air Flow sensor	MAF sensor	MAF sensor
Microprocessor Control Unit	MCU	
Neutral Drive Switch	NDS	
Neutral Gear Switch	NGS	
New Generation Star Tester	NGS	
Octane Adjust	OCT ADJ	
Power Steering Pressure Switch	PSPS	PSP
Pressure Feedback EGR sensor	PFE sensor	
Profile Ignition Pickup	PIP	
Programmable Speedometer/Odometer Module	PSOM	
Self-Test Automatic Readout tester	STAR tester	
Self-Test Connector		DLC
Self-Test Input	STI	
Self-Test Output	STO	
Sequential Electronic Fuel Injection	SEFI	SFI
Service Bay Diagnostic System	SBDS	
Signal Return	SIG RTN	
Spark Angle Word	SAW	
Spark Output	SPOUT	
Speed Control Command Switches	SCCS	
Temperature Compensated Pump	TCP	
Thermactor Air Bypass	TAB	
Thermactor Air Diverter	TAD	
Thick Film Integrated	TFI	
Throttle Air Bypass	TAB	
Throttle Kicker	TK	
Throttle Position sensor	TP sensor	TP sensor or TPS
Vane Air Flow meter	VAF meter	
Vane Air Temperature sensor	VAT sensor	IAT
Variable Reluctance Sensor	VRS	
Variable Venturi	VV	
Variable Voltage Choke	VVC	
Vehicle Power	VPWR	
Voltage Reference	VREF	

Figure B–4 Ford Motor Company terms and acronyms.

DaimlerChrysler Term	DaimlerChrysler Acronym	OBD II Acronym
Actuator Test Mode	ATM	
Adaptive Fuel Control		LTFT/STFT
Automatic Idle Speed	AIS	IAC
Automatic Shutdown relay	ASD relay	
Backpressure EGR	BPEGR	BPEGR
Barometric Pressure Read solenoid	BARO Read	
Charge Temperature sensor		IAT sensor
Coolant Temperature Sensor	CTS	ECT sensor
Diagnostic Readout Box	DRB I, II, III	
Direct Ignition System	DIS	
Distance Sensor	DS	VSS
Electronic Lean Burn	ELB	
Electronic Spark Advance	ESA	
Electronic Spark Control	ESC	
Engine Control Unit	ECU	PCM
Exhaust Gas Recirculation	EGR	EGR
Heated Oxygen Sensor	HO_2S	HO_2S
Jeep/Truck Engine Controller	JTEC	
Knock Sensor	KS	KS
Manifold Absolute Pressure sensor	MAP sensor	MAP sensor
Mass Air Flow sensor	MAF sensor	MAF sensor
Next Generation Controller	NGC	
Oxygen Sensor	O_2S	O_2S
Power Loss Lamp	PLL	MIL
Sequential Fuel Injection	SFI	SFI
Single Board Engine Controller	SBEC I, II, III, IIIa	
Single Module Engine Controller	SMEC	
Throttle Body Injection	TBI	TBI
Throttle Position Sensor	TPS	TP sensor or TPS

Figure B–5 DaimlerChrysler Corporation terms and acronyms.

Nissan Term	Nissan Acronym	OBD II Acronym
Absolute Pressure Sensor		MAP/BARO
Adaptive Fuel Control	ALPHA	LTFT/STFT
Auxiliary Air Control valve	AAC valve	IAC
Camshaft Position sensor	PHASE	CMP sensor
Crankshaft Position sensor	REF/POS	CKP sensor
Electronic Concentrated Control System	ECCS	
Engine Control Unit	ECU	PCM
Engine Coolant Temperature sensor	ECT sensor	ECT sensor
Exhaust Gas Recirculation	EGR	EGR
Heated Oxygen Sensor	HO_2S	HO_2S
Idle Air Control Valve	IACV	IAC
Intake Air Temperature sensor	IAT sensor	IAT sensor
Mass Air Flow sensor	MAF sensor	MAF sensor
Oxygen Sensor	O_2S	O_2S
Sequential Fuel Injection	SFI	SFI
Throttle Position Sensor	TPS	TP sensor or TPS

Figure B–6 Nissan terms and acronyms.

Toyota Term	Toyota Acronym	OBD II Acronym
Engine Control Unit	ECU	PCM
Engine Coolant Temperature sensor	ECT sensor	ECT sensor
Exhaust Gas Recirculation	EGR	EGR
Heated Oxygen Sensor	HO_2S	HO_2S
Intake Air Temperature sensor	IAT sensor	IAT sensor
Manifold Absolute Pressure sensor	MAP sensor	MAP sensor
Mass Air Flow sensor (air flow meter)	MAF sensor	MAF sensor
Oxygen Sensor	O_2S	O_2S
Sequential Fuel Injection	SFI	SFI
Throttle Position Sensor	TPS	TP sensor or TPS
Toyota Computer-Controlled System	TCCS	

Figure B–7 Toyota terms and acronyms.

Honda Term	Honda Acronym	OBD II Acronym
Constant Vacuum Control valve	CVC valve	
Crank Angle sensor	CA sensor	CKP sensor
Electronic Air Control Valve	EACV	IAC
Engine Control Unit	ECU	PCM
Exhaust Gas Recirculation	EGR	EGR
Heated Oxygen Sensor	HO_2S	HO_2S
Idle Mixture Adjuster	IMA	MC solenoid
Manifold Absolute Pressure sensor	MAP sensor	MAP sensor
Mass Air Flow sensor	MAF sensor	MAF sensor
Oxygen Sensor	O_2S	O_2S
Pressure Absolute sensor	PA sensor	BARO sensor
Programmed Fuel Injection	PGM-FI	
Sequential Fuel Injection	SFI	SFI
Temperature Air sensor	TA sensor	IAT sensor
Temperature Water sensor	TW sensor	ECT sensor
Throttle Angle Sensor	TAS	TP sensor or TPS

Figure B–8 Honda terms and acronyms.

Appendix C

Automotive-Related Web Addresses

Publisher

Delmar Cengage Learning (*formerly* Thomson Learning): http://www.delmar.cengage.com/

General Automotive-Related Web Addresses

California Air Resources Board: http://www.arb.ca.gov/homepage.htm

Environmental Protection Agency: http://www.epa.gov

Fuel Cell Store: http://www.fuelcellstore.com

General Motors' Mode $06 data: http://service.gm.com/gmspo/mode6/index.html

How Stuff Works: http://www.howstuffworks.com

Scan Tools and Lab Scopes

AES Wave: http://www.aeswave.com

Fluke Corporation: http://www.fluke.com

Snap-on Tools: http://www.snapon.com

PC-Based Scan Tools and Lab Scopes

AutoEnginuity: http://www.autoenginuity.com

Automotive Test Solutions: http://www.automotivetestsolutions.com

AutoTap: http://www.autotap.com

EASE Diagnostics: http://www.OBD2.com

Professional Organizations

Automotive Service Excellence (ASE): http://www.ase.com

Identifix: http://www.identifix.com

International Automotive Technicians' Network: http://www.iatn.net

National Automotive Technicians Education Foundation (NATEF): http://www.natef.org

North American Council of Automotive Teachers (NACAT): http://www.nacat.com

Society of Automotive Engineers: http://www.sae.org/servlets/index

Training

ATech: http://www.atechtraining.com

Lincoln College of Technology, Denver, Colorado (*formerly* Denver Automotive & Diesel College): http://www.lincolnedu.com/campus/denver-co

Lincoln Educational Services: http://www.lincolnedu.com

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Glossary

A4LD transmission (automatic four-speed light-duty)—An overdrive transmission featuring a PCM-controlled torque converter clutch for rear-wheel-drive vehicles.

AC—A parts manufacturing and distribution division of General Motors.

Accumulator—A reservoir located between the evaporator (under-dash unit) and the compressor of an air-conditioning system. It allows refrigerant and any remaining liquid to separate. Also used to describe a component in any hydraulic circuit (such as an automatic transmission) that moderates the application of some clutch or band.

Active command—A command sent to a PCM or other control module that commands or instructs the module to energize and de-energize an actuator or other output circuit.

Active Fuel Management (AFM)—A variable displacement system in which the PCM disables cylinders to improve fuel economy when engine load is light. The selected cylinders are disabled by turning off the fuel injector and spark and then disabling the ability of the valves to open through a specially designed lifter, thus reducing pumping losses by allowing the cylinder to act as an air spring.

Active voltage—A voltage that is actively pulled either high or low by a computer circuit.

Actuator—Any mechanism, such as a solenoid, relay, or motor, that when activated causes a change in the performance of a given system or circuit.

Adaptive cruise control—A cruise control system that can reduce engine torque and even apply the brakes lightly to maintain a preset gap to a vehicle ahead.

Adaptive memory—The ability of an engine control computer to assess the success of its actuator and sensor signals and modify its internal calculations to correct them if the desired result is not achieved.

Adaptive strategy—The internal programs by which the Ford PCM learns from the results of its monitoring of sensors and activation of actuators and then modifies its programming to better achieve driveability, emissions, and fuel economy objectives.

AdvanceTrac^{TM}—A modified antilock brake and traction control system used by Ford that can pulse the brakes at any single corner of a vehicle to correct either understeer or oversteer. The control module can also reduce engine torque as needed.

Alternate fuel compatibility—The ability of an engine to run on various fuels. The first step is the use of methanol- and ethanol-compatible seals and other parts in the fuel delivery system. The use of entirely different fuels, such as natural gas, is predicted to be the next step toward fuel economy.

Amp or **Ampere—**A measurement of electrical current flow within a circuit; equal to 6.25 billion billion electrons passing a given point in 1 second.

Amperage—Current that is flowing in a circuit.

Amplitude—The difference between the high value and the low value in the voltage or current waveform of a signal.

Ampule—A strong glass tube that forms the body of an electrical component such as a vacuum tube.

Analog—A signal that continuously varies within a given range and with time taken for the change to occur.

Anode—A conductor with positive voltage potential applied.

Arbitration—The process of determining which node can continue to transmit data on a bus when two or more nodes begin transmitting data at the same time.

Armature—A winding of wire designed to create a strong electromagnetic field when current is flowing through it.

Asynchronous—Data sent on a data bus intermittently and as needed, rather than in a steady stream.

AXOD (automatic transaxle overdrive)—A four-speed automatic transmission featuring a PCM-controlled torque converter clutch used in some front-wheel-drive vehicles.

Background noise—Modern knock sensors are effective microphones informing the computer of all the engine's internal sounds, which the computer then sorts out for frequencies characteristic of knock. By tracking the increase in background noise with higher engine speed and load, the computer can test the effectiveness of the newer type of knock sensor.

Barometric pressure—The actual ambient pressure of the air at the engine. Because this pressure varies somewhat with the weather and altitude, the information is needed to correctly determine air/fuel mixture.

Baud rate—A variable unit of data transmission speed (as one bit per second). In a stream of binary signals, one baud is one bit per second. Baud refers to the speed at which information can be sent and received over a data bus. The limitation comes from the sending and receiving units, not from the wire itself. Many modern automotive computers can transmit and receive at a baud in excess of 10,000. The term *baud* is in honor of the Frenchman J. M. E. Baudot, who is responsible for much of the early development of unit data transmission.

Belt Alternator Starter (BAS)—A mild hybrid system on General Motors vehicles that uses an electric motor/generator (EMG) that operates as both a 42-V alternator and a 36-V starter. The EMG is belt-driven by the crankshaft and can also belt-drive the crankshaft.

Bidirectional controls—The ability of a scan tool to send commands to the PCM or other control module in order to initiate an active command.

Binary code—This is the form of all the signals transferred on a data bus. It consists of a series of on/off signals corresponding to the digits of the binary numbers, each with a designated meaning. Binary code transfer is very fast.

Bit—A single piece of information in a binary code system; somewhat comparable to a single letter within a word or a single digit within a number.

Block learn—The adaptive memory systems used on General Motors cars. As the vehicle ages and driving conditions change (such as seasonal weather or altitude), the computer can make immediate and semi-permanent changes to the fuel mixture and spark maps in its keep-alive memory to optimize driveability, emissions, and fuel economy.

Breakout box (BOB)—A diagnostic tool using special connectors and a terminal box that enables the technician to check voltages on all circuits of a harness while the system is in operation.

Byte—Eight pieces of binary code information strung together to make a complete unit of information. Certain newer onboard computers recognize either 16 or 32 bits of information as representing a byte (known as 16-bit or 32-bit computers).

C3I—A name used by General Motors to describe its three-coil ignition system with a module instead of a distributor.

CALPAK—A removable part of the PCM that plugs in like the PROM and is primarily responsible for storing information regarding fuel injection calibration. Used on the GM 2.0-L engine.

Capacitor—An electric storage device used in most pressure sensors by Ford EEC IV systems. The unit's capacitance is transformed into a frequency signal internally and sent to the PCM.

Carbon dioxide (CO_2)—A molecule that contains one carbon atom and two oxygen atoms. A nontoxic emission produced by proper combustion taking place in the engine with enough oxygen present. CO_2 levels are an indication of combustion efficiency, with high CO_2 levels desired.

Carbon monoxide (CO)—An oxygen-starved molecule that contains one carbon atom and one oxygen atom. A toxic emission produced by combustion taking place in the engine with a shortage of oxygen present. A CO molecule will eventually seek out an oxygen atom and transform itself to CO_2. In the interim, exposure to CO can cause headaches, dizziness, nausea, and death. CO has no taste, odor, or color and cannot be detected by human senses.

Catalyst—An agent that causes a chemical reaction between other agents without being changed itself.

Cathode—A conductor with negative voltage potential applied.

Central Multiport Fuel Injection (CMFI)—A fuel injection system used by General Motors on Vortec engines that delivers fuel from a single, centrally located fuel injector through nylon tubes and spring-loaded poppet valves to spray fuel on the back side of each cylinder's intake valve. As a result, only air is moving through the intake manifold, similar to most port-injected engines.

Central Sequential Fuel Injection (CSFI)—A fuel injection system used by General Motors on Vortec engines that is similar to the CMFI system except that multiple injectors are used to deliver fuel to each cylinder by way of nylon tubes and poppet valves. The injector solenoids are centrally located between the upper and lower halves of the intake manifold.

Clamping diode—A diode placed across a coil or winding to trap the voltage spikes produced when the device is turned off.

Clock oscillator—The electronic device within every computer that produces a continuous stream of voltage pulses. The frequency of these pulses establishes the computer's clock speed.

Close-coupled catalytic converter—Catalytic converters that are mounted directly adjacent to the exhaust manifolds, thereby allowing them to reach operating temperature more quickly following a cold start.

Closed loop—The triangular relationship between a computer, an actuator, and a sensor that allows the computer to monitor the results of its own actuator control through a feedback signal from the sensor (or circuit). This concept may be used with certain computer-controlled actuators or systems such as air/fuel ratio control, EGR control, fuel pump and ignition system monitoring, Electronic Automatic Temperature Control (EATC) systems, antilock brake systems, and speed control systems.

Closed loop/open loop—Closed loop is the mode in which the computer adjusts the air/fuel mixture in response to signals from the oxygen sensor, which in turn respond to the changed mixture ratio. Open loop refers to control of the mixture based on other information inputs, but not the oxygen sensor signal.

Component ID (CID)—An identification code, usually a hexadecimal value, that identifies a component in a computerized engine control system. CIDs and their related information can be displayed using a scan tool. The related specifications often may be looked up at a manufacturer's Web site.

Compound—A molecule that contains atoms of two or more elements.

Computer Controlled Coil Ignition (C3I)—A waste spark ignition system using Hall effect CKP and CMP sensors. Introduced by General Motors in 1984.

Concentration sampling—A method of gas analysis used today by most gas analyzers in automotive shops. It has a probe that is inserted into the exhaust pipe. The probe allows the analyzer to sample only a small percentage of the total exhaust gas volume. Each of the gasses is measured as a percentage, or concentration, of the total sample. The resulting measurements are expressed as either percent or parts per million (ppm), with ppm simply being a smaller proportion.

Constant volume sampling (CVS)—A method of gas analysis that requires that all of the exhaust be captured and measured along with enough ambient air to create a known volume of gasses. Then the density of this known volume is calculated. Finally, the concentration (percentage) of each gas is calculated to determine how many grams of each gas is being expelled from the exhaust system. The analytical computer is also able to use dynamometer readings to determine the distance that the vehicle has traveled in any instant in time or over a longer time period. At this point each gas is calculated as grams per mile (GPM).

Continuous injection—One of the two kinds of fuel injector fuel-spray techniques, the other being pulsed injection. A continuous injector (basically limited to the Bosch K-Jetronics systems) sprays fuel whenever the engine is running. The quantity of fuel injected is determined not by the injectors but by the fuel distributor, a separate component.

Continuously variable transmission (CVT)—A transmission that transfers optimum torque from either a gasoline engine or an electric motor (or from both) to the drive wheels regardless of vehicle speed or load. The driver never has to "shift gears" as with normal multispeed transmissions.

Continuous monitor—A monitor that is monitored continuously by the PCM.

Conversational Speech Interface Technology—A voice recognition technology used by Ford that allows the driver and/or passenger to carry on a normal dialogue with the vehicle. The resulting dialogue on the part of the vehicle sounds more like a real person than a robot. Equipped with a 50,000-word vocabulary, the driver/passenger does not have to memorize specific voice commands, as do some voice recognition systems.

Current ramping—The use of a lab scope (digital storage oscilloscope, or DSO) to look at current waveforms of load components or actuators, using a low-current probe to capture the waveform. The name comes from the fact that current builds slowly when turned on, causing an upslope, or upward ramp, to appear on the waveform.

Data bus network—The data bus network is the information transfer harness between the elements on a multiplexing system. In some vehicles, this consists of a special pair of twisted wires going to each element. The wires are twisted to prevent introduction of spurious signals from electrical fields generated by speed sensors, horn and headlight circuits, radios (particularly high-power or CB), and spark plug cables. Many newer systems use a single-wire data bus design. The serial data on a single-wire bus has a waveform that is trapezoidal in shape. This allows the nodes that are communicating on the bus to distinguish between the sharp change of an induced voltage spike and a binary bit of information.

Data link connector (DLC)—The 16-terminal connector on an OBD II vehicle that allows a scan tool to be connected to communicate with the onboard computers. When connected to the DLC, the scan tool becomes a node on the data busses that connect to the DLC. Sometimes also called a "diagnostic link connector."

Data stream—The communication between a scan tool and an onboard computer when the scan tool is connected to the data link connector (DLC) and the ignition switch is turned on. The communication is in the form of binary code (serial data); it allows either one-way or two-way communication between the scan tool and the onboard computers.

Demultiplexor—An electronic chip that, when built into a node, gives it the ability to receive and decipher messages on a data bus.

Diagnostic routines—A section in the service manual that lists possible causes of a driveability complaint. It is the beginning point of the diagnostic procedure once the complaint has been verified.

Diagnostic trouble code (DTC)—A set of alphanumeric sequences the computer stores in its memory when it senses failures in certain sensor or actuator circuits. *DTC* is the term used in OBD II literature; *trouble codes* or *fault codes* were the terms used before OBD II.

Digital—A voltage signal that is either of two voltage values but does not vary in a continuous fashion between them. Typically these signals will be a voltage that is turned either on or off but may also vary between two voltage values that are both above ground. On a lab scope, the change of voltage (either high or low) shows a sharp, vertical edge.

Digital storage oscilloscope (DSO)—A lab scope that displays a computer-generated waveform that may be frozen, measured, stored, downloaded to a PC, and printed out. The on-screen adjustments include coupling, ground level, volts per division, time per division, and trigger characteristics; they are similar to an analog lab scope. A DSO is most often used to capture voltage waveforms over the time shown on the screen but may also be configured with a low-current probe to capture current waveforms (known as *current ramping*). A DSO is designed to perform pinpoint tests of a circuit or component.

Digital volt ohmmeter (DVOM)—A diagnostic tool that allows the technician to view numerical readings relating to voltage, amperage, and resistance measurements. Many DVOMs can also be used to measure frequency, duty cycle, pulse width, RPM, and temperature. High-end units also may include a bar graph to improve update resolution. Auto-scaling DVOMs are designed to rescale automatically according to the values being measured. A DVOM is designed to perform pinpoint tests of a circuit or component.

Diode—The simplest semiconductor, consisting of only two semiconductor elements placed back-to-back. A diode operates as an electrical one-way check valve with no moving parts.

Direct ignition/waste spark ignition—A direct ignition system eliminates the ignition distributor and fires spark plugs directly from the coil. If the direct ignition system is of the waste spark type, each coil fires two spark plugs simultaneously. One spark occurs at the end of its cylinder's compression stroke, just before the power stroke; the other spark occurs at the cylinder 360 degrees apart in firing order from the first, during the end of that cylinder's exhaust stroke. The two sparks are of opposite polarity. Non–waste spark direct ignition systems use one coil per spark plug.

Displacement on Demand (DOD)—General Motors' original name for their Active Fuel Management (AFM) system, which is a variable displacement system in which the PCM disables cylinders to improve fuel economy when engine load is light. The selected cylinders are disabled by turning off the fuel injector and spark and then disabling the ability of the valves to open by use of a specially designed lifter, thus reducing pumping losses by allowing the cylinder to act as an air spring.

Driveability—Those factors, including ease of starting, idle quality, and acceleration without hesitation, that affect the ease of driving and reliability.

Drive cycle—A series of operating conditions that allows the PCM to complete all of the OBD II emissions-related monitors.

Dual in-line package (DIP)—Refers to an integrated circuit chip with two rows of legs (terminals).

Duty cycle—The portion of time during each cycle when an electrical device is turned on, when the device is cycled at a fixed number of cycles per unit of time.

E-cell—A module containing a cathode and an anode, each of which is gradually sacrificed as current passes through it, eventually causing the circuit to open.

EEPROM—Electronically erasable programmable read-only memory, an improved and updated type of PROM. Like the PROM, it can retain tabular information for the PCM even if power is withdrawn from the computer. Unlike the PROM, the information in this memory can be changed by the computer. Also unlike the PROM, the EEPROM is a nonreplaceable part of the computer.

Efficiency monitoring—The diagnostic testing performed by a computer, specifically in its ability to compare input values to each other, or to operate an actuator while watching the change in a related input circuit. Also known as *rationality testing.*

EGR temperature sensor—On late-model cars, particularly those that are OBD II–compliant, the EGR temperature sensor serves to signal the computer that recirculated exhaust gas flows when it sends the command for it to do so. This sensor makes use of the fact that the exhaust gas is very hot, so the temperature of the passage provides a reliable indicator of exhaust flow.

Electrical—Refers to a circuit that performs physical work in the creation of heat, light, or magnetism. An electrical circuit operates at relatively high amperage. An electrical circuit may or may not be controlled electronically.

Electrical schematic—A map of an electrical system's circuitry that can be used by the technician as a diagnostic aid. It is most often used to increase the level of understanding of an unfamiliar system.

Electromotive force—Refers to the electrical pressure that pushes current flow. It is commonly called voltage and is measured in volts.

Electronic—Refers to solid-state control circuits that are placed in control of electrical circuits. Electronic circuits operate at relatively low amperage and consist of solid-state electronic parts such as diodes and transistors.

Electronic Throttle Control (ETC)—A system, sometimes referred to as "drive-by-wire," that physically decouples the throttle pedal from the throttle plate(s), thus eliminating the traditional throttle cable. An accelerator pedal position (APP) sensor provides the driver demand information to the PCM; the TPS simply provides a feedback signal. The PCM then controls the position of the throttle plate(s) through pulse-width modulated control of a DC motor. Formerly known by General Motors as a Throttle Actuator Control (TAC) system, this system increases the responsiveness of the engine.

Element—A molecule that has only one type of atom, as shown in the periodic table, defined by how many protons, neutrons, and electrons the atom contains.

Enable criteria—The specific operating conditions of the engine and the vehicle that are required to be present before the PCM will perform a test such as a drive cycle or a trip. When the pre-programmed enable criteria have been met, the PCM will perform a drive cycle to test one or more monitors. When the PCM needs to verify the presence or absence of a fault, it will perform a trip with the enable criteria aimed specifically at the particular fault.

Engine calibration—Adjustments or settings that produce desired results, such as spark timing, air/fuel mixture, and EGR control.

Engine calibration assembly—The portion of a Ford PCM that contains the necessary programming to fine-tune the PCM's commands to the specific needs of a particular vehicle, similar to a PROM chip on a General Motors vehicle. On EEC I, EEC II, and EEC III systems, the calibration assembly is attached externally to the PCM, is removeable, and contains an octane adjustment switch. On EEC IV and EEC V systems, the calibration assembly is a permanent part of the PCM.

Engine metal overtemp mode—A unique feature of the Aurora/Northstar engine, whereby under circumstances of very high engine temperature (if, for example, the coolant has leaked out), the computer selectively disables four of the fuel injectors to prevent a temperature that would cause permanent mechanical damage to engine components.

EVAP system pressure sensor—Used on many OBD II–compliant vehicles to test the fuel vapor canister system for leaks. On many vehicles, special plumbing allows the MAP sensor to provide this function during the period between ignition on and engine running.

Exhaust gas analyzer—A diagnostic machine that samples and displays measurements of automotive emissions readings, including HC, CO, CO_2, and O_2, for diagnostic purposes. Additionally, some analyzers also measure and display readings for NO_x.

Fail-Safe Cooling—Ford's name for the ability of the PCM to disable fuel injectors to allow the respective cylinders to simply pump air to cool the block and cylinder heads.

Feedback—Refers to a signal from a circuit or sensor that allows a computer to monitor the results of its own control in a closed-loop fashion.

Flow bench—A specialty tool, chiefly used at carmakers' factories, to properly set feedback carburetors to deliver proper air/fuel mixtures. The settings determined on a flow bench are normally marked with paint to indicate that they are not to be changed.

Flowcharts—A series of diagnostic charts that are designed to guide the technician through the necessary pinpoint tests to identify the exact cause of a fault.

Flywheel Alternator Starter (FAS)—a mild hybrid system on General Motors vehicles that uses an electric motor generator (EMG) operating as both a 42-V alternator and a 36-V starter. The EMG is built into a redesigned torque converter in the area of the transmission's bell housing.

Free electrons—Electrons that are loosely held in an atom's orbit. These electrons can be pushed from one atom to another if enough voltage is applied to overcome their resistance to moving.

Freeze frame data—Whenever an OBD II diagnostic trouble code is set, the computer records the information pertaining to the sensors, actuators, and operating conditions that are relevant to the fault. This information can be pulled from the computer's memory with a scan tool and is designed to aid the technician in diagnosis.

Front and rear oxygen sensors—To ensure that the engine control system can go into closed loop quickly, both the front and rear oxygen sensors include heater circuits to get them to operating temperature quickly.

Front Electronic Module (FEM)—A Ford control module that controls the one-touch-down power window, the horn relay, and the exterior lighting at the front of the vehicle.

Fuel cell vehicle (FCV)—A version of an electric vehicle that uses hydrogen fuel cells to provide the electrical power that the motor (or motor/generator) uses to accelerate the vehicle's drive wheels.

Fuel temperature sensor—On some cars, a sensor mounted in or near the fuel tank to inform the computer of the fuel temperature. This information is used to calculate fuel viscosity and susceptibility to vapor lock.

Fuel trim—The ability of the PCM to modify the base fuel calculation to maintain a stoichiometric air/fuel ratio while in closed loop. Fuel trim is divided into both a short-term fuel trim (STFT) and a long-term fuel trim (LTFT).

Functional test—A test (that has been programmed into a computer) designed to aid the technician in diagnosing faults in the controlled system. For example, a functional test may allow the technician to energize certain actuators as desired.

Gallium arsenate crystal—A semiconductor material that changes its conductivity when exposed to a magnetic field.

Generic Electronic Module (GEM)—A Ford control module that controls body functions such as interval wipers, the driver's door one-touch-down power window, the illuminated entry feature, and other features. Similar to the BCM (Body Control Module) on General Motors and Chrysler vehicles except that it does not control the climate control system. On newer Ford products, the GEM was separated into two control modules: the FEM and the REM.

Generic OBD II Mode—A scan tool diagnostic mode designed to allow an aftermarket generic scan tool access to nine generic diagnostic modes out of fifteen set aside by the EPA under OBD II standards. Also known as *Global OBD II Mode* by some scan tool manufacturers.

Global OBD II Mode—The name that some scan tool manufacturers give to *Generic OBD II Mode.*

Grade Logic Control—A control module strategy used by Honda, designed to reduce the driver's need to constantly compensate at the throttle pedal for transmission upshifts and downshifts when driving in mountainous terrain.

Grams per mile (GPM)—A measurement of exhaust gasses using a constant volume sampling (CVS) method in conjunction with a dynamometer.

Grid—A fine wire mesh that is placed between the anode and cathode segments of a vacuum fluorescent display (VFD).

H-gate—Two pairs of transistors used to control current flow direction.

Hall effect switch—A magnetic switching device often used to signal crankshaft position and speed to the computer.

Hard fault—A fault that currently exists.

Hard wiring—Wiring designed to carry only one type of signal 100 percent of the time, unlike a data bus that can transmit multiple messages. For example, a throttle position sensor (TPS) signal wire is traditionally used to communicate information about throttle position to the PCM 100 percent of the time.

Hexadecimal—A system of assigning single digits to represent the total decimal value of four bits of binary code. The values 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F are used, thus creating a "base-16" numbering system. Hexadecimal values are often represented using a dollar sign ($) ahead of the value. Also referred to as a "hex" value.

High-pressure cutout switch—A pressure-operated switch in the high-pressure side of the air-conditioning system that opens when pressure climbs too high. When the switch opens, it disables the A/C compressor clutch circuit.

High-voltage (HV) battery—An onboard battery made up of many cells to create a voltage potential of several hundred volts. Used on gasoline/electric hybrid-drive vehicles.

Home energy station (HES)—A device that uses tap water with electricity from a wall outlet to create the hydrogen needed to refill a fuel cell vehicle's hydrogen tanks.

Hot-film air mass sensor—A type of air mass sensor using changes in the temperature of the heated element to determine the mass of the air passing into the engine.

Hot-wire air flow sensor—An air flow sensor that keeps a special wire at a fixed number of degrees above ambient temperature in the intake airflow. The amount of current required to maintain the heat is converted into a voltage or frequency signal that conveys information about the mass of the intake air.

Hydrocarbons (HC)—A vehicle emission consisting of unburned gasoline or diesel fuel. The engine may produce excessive HCs due to a total misfire or rich air/fuel conditions. HCs may also be released into the atmosphere because of fuel evaporation.

Hz (Hertz)—Cycles per second; a measure of frequency.

Idle tracking switch—An on/off switch indicating to the computer that it is in charge of the engine for idle speed.

Impedance—The total circuit resistance, including resistance and reactance.

Inductive pickup/Hall effect pickup—Two types of rotation sensors are used on many vehicles: the inductive pickup and the Hall effect. Inductive pickups consist of a wire coil wound around a permanent magnet. When a metal tooth passes the tip of the magnet, a small, polarity-reversing alternating current is generated (this current can grow much larger with higher speed). The Hall effect pickup receives a reference voltage from the computer and converts it into an on/off signal. Hall effect sensors do not vary the signal voltage output with speed.

Inertia switch—A Ford trademark safety feature and an occasional no-start puzzle. To protect against a gasoline fire following an accident, the inertia switch disables the fuel pump circuit upon impact.

Initialization mode—The beginning state of an engine control computer when the ignition switch has been turned to on but the engine has not yet started. The computer performs a variety of internal tests and sensor/actuator checks.

Intake Manifold Runner Control (IMRC)—An intake air plenum design used on Ford and Mazda engines that can vary the effective length of the intake. When the engine is operating at low speed and under light load, it provides a longer effective length to keep the velocity of the air flow high so as to provide crisp throttle response. When engine speed and load are increased, it provides a shorter effective length to allow for additional air flow to meet the greater demand.

Integrated circuit (IC)—A circuit, typically placed on a semiconductor chip, that is minuscule in size and consists of semiconductor components such as diodes and transistors.

Integrator—A term that refers to the General Motors name for short-term fuel trim (STFT) prior to OBD II standardization, referring to the PCM's immediate reaction to the last voltage signal communicated from the oxygen sensor.

Intelligent Architecture—A system that includes a combination voice recognition and navigational system, as well as the ability to personalize driver settings or download information or music. The system also has several other features, including the ability to communicate with electronic devices using Bluetooth^{TM} wireless technology. Also included is real-time navigation, a feature that can alert the driver to an accident ahead or even remind him/her of a vehicle service that is due. Another feature, called "MyHome," gives the driver the ability to communicate with Web-based equipment at home or elsewhere.

Interface—Circuitry that converts both input and output information to analog or digital signals as needed and filters external circuit voltage to protect computer circuits.

Intrusive test—A self-test initiated by the PCM to test a non-continuous monitor. During this test the PCM energizes output actuators, not because engine/vehicle operating conditions warrant it, but only for the purpose of performing the test.

KAM—Keep-alive memory, an electronic memory in the computer that must have a constant source of voltage to continue to exist.

Kilobyte—1024 bytes of information in binary code.

Lambda—A Greek letter (Λ) used to indicate how far the actual air/fuel mixture deviates from the ideal air/fuel mixture. Lambda equals actual inducted air quantity divided by the theoretical air required (14.7). The actual ideal mixture depends on the characteristics of the fuel and air drawn in through the intake system.

Lift pump—An electric fuel pump in or near the fuel tank that pressurizes the fuel slightly (about 15 psi) and delivers it to the main fuel pump. Found on both gasoline and diesel engines. Sometimes called a *primer pump.*

Light-emitting diode (LED)—A semiconductor device that generates a small amount of light when forward biased (when voltage is applied with the polarity such that current flows across the PN junction).

Limp-in mode—A state of a computer engine management system in which one or more major component circuits have failed and a substitute value is used to retain driveability until the vehicle can be repaired.

Linear air/fuel (LAF) sensor—A wideband oxygen sensor designed to accurately measure leaner air/fuel ratios than can be measured with a standard oxygen sensor. The use of an LAF sensor allows the PCM to run the engine quite lean under certain conditions.

Logic gates—Combinations of transistors within the computer that determine the computer's output reaction to a specific combination of inputs values.

Logic module and power module—Early to mid-1980s Chrysler products separated the computer functions into two components: the power module, which carried the higher current and worked the actuators, and the logic module, usually in a more protected place, usually more electrically protected. The logic module assesses sensor inputs and instructs the power module when to inject fuel, fire plugs, and work actuators.

Logic probe—A computer-safe test light using LEDs to indicate if a signal is present. Logic probes are typically used to provide quick checks of primary ignition and fuel injector circuits.

Long-term fuel trim (LTFT)—A long-term adjustment made within the PCM so that the performance of the short-term fuel trim (STFT) will cause the oxygen sensor signal to average between 400 and 500 mV. LTFT is designed to modify the base fuel calculation to compensate for wear and aging of the engine and other components that affect the air/fuel ratio. Originally known on General Motors' products as "block learn."

Longitudinal—Parallel to the length of the car (opposed to transverse).

Loop configuration—A configuration of a multiplexing network that connects the data bus to all nodes on the bus in a series circuit.

Malfunction indicator light (MIL)—A lamp on the instrument panel used to alert the driver when the PCM identifies a problem with the engine control system. Known commonly as a *check engine light* prior to OBD II standardization.

Manifold absolute pressure (MAP)/intake manifold vacuum—Manifold absolute pressure (MAP) is the actual pressure in the intake manifold, regardless of the difference between it and ambient air pressure. *Intake manifold vacuum,* the traditional concept, refers to the relative difference in pressure between the two. Intake manifold vacuum is always a relative measure. MAP measurements are not relative.

Master—The computer that controls a data bus network.

Megabyte—1,048,576 (1024 squared) bytes of information in binary code.

Memory—A computer's information storage capability.

Memory DTC—A diagnostic trouble code (DTC) that has been set in a computer's memory at some point in the past. This type of DTC may represent either a hard fault or a soft fault.

Micron—A unit of measurement that describes the size of a particle one-millionth of an inch in diameter.

Microprocessor—A processor contained on an integrated circuit; a processor (central processing unit) that makes the arithmetic and logic decisions in a microcomputer.

Misfire detection—Part of the required OBD II program, misfire detection closely monitors engine RPM for the slight variations when combustion misfire occurs. In most cases, the computer disables the injector for a misfiring cylinder (to protect the catalytic converter from overheating) and sets an appropriate DTC.

Modulate—To find a position between two extremes; to alternate between on and off.

Modulated displacement—A system in which a series of PCM-controlled electromechanical devices can selectively disable the rocker arms of particular cylinders, preventing the valves from opening. The engine then operates on eight, six, or four cylinders, depending on power requirements.

Molecule—A small chemical building block that consists of two or more atoms. It may be an element or a compound.

Monitor—An onboard diagnostic test that an OBD II PCM performs to determine if a component or system is within design specifications.

Motor/generator (MG)—A component that can turn electrical energy into mechanical energy (as a motor does) and can also turn mechanical energy into electrical energy (as a generator does). Also sometimes referred to as an electric motor/generator (EMG).

Motor start-up in-rush current—The initial high current that an electrical motor draws when its circuit is first energized.

Motronic—The latest of the Bosch engine management systems, Motronic is Bosch's first full engine control system, regulating fuel injection and ignition timing and dwell in one unit.

Multiplexing (MUX)—One of the most significant extensions of computer control technology in vehicles, multiplexing connects many or all the control units in a vehicle over a single-wire network: the data bus. Information from all components is sent over the data bus and received by all.

Multiplexor—An electronic chip that, when built into a node, gives the node the ability to send messages on a data bus.

Negative ion—An atom that has an extra electron, thus having more electrons than it has protons. It therefore has a negative electrical charge.

Nitrogen (N_2)—A gas that makes up approximately 78 percent of Earth's atmosphere. Ideally, the nitrogen that enters the engine's combustion chambers will go through unchanged.

Node—A computer that is connected to a data bus and has the ability to send and/or receive messages on the bus.

Noise-vibration-harshness (NVH)—A special acoustic diagnosis tool that can identify the frequencies of various noises and vibrations to compare with known frequencies. Useful to determine whether a noise or vibration is engine-speed-relative, drivetrain-speed-relative, wheel-speed-relative, or random.

Non-continuous monitor—An OBD II monitor that is not continually monitored by the PCM, but rather is tested by the PCM performing an intrusive test of the component or system. A non-continuous monitor is only run when specific preprogrammed enable criteria are met.

Non-powered test light—A tool that can be used to quickly check for a voltage potential (differential). Voltage potential should not be judged based on the brightness of the light. Unfortunately, due to its low internal resistance, a test light can act as a jumper wire and unexpectedly damage a computer or deploy an air bag.

Normally aspirated—An engine that uses ambient atmospheric pressure to force air into the engine (as opposed to turbocharged and supercharged).

OBD II—A standardized computer control self-diagnostic program, mandated for most vehicles as of the 1996 model year. Nomenclature, trouble codes, and even the size, shape, and many circuits of the diagnostic connector are standardized across the industry.

Ohm—A unit of measurement used to measure electrical resistance.

Ohm's law—An electrical law that states that it takes 1 V of electrical pressure to push one amp of current flow through 1 Ω of resistance.

On-demand DTC—A diagnostic trouble code (DTC) that results from a self-test (performance test), identifying any hard faults that were found within the computer system.

Open loop—Any operational mode in which a computer controls an output circuit but does not use a feedback signal from a sensor or circuit to monitor the results of its own control. However, the computer may monitor other input signals/sensors during open-loop control that do not pertain to a feedback signal. In the PCM's open-loop control of the air/fuel ratio, the air/fuel mixture is calculated based on coolant temperature, engine speed, and engine load without benefit of the oxygen sensor. *See also* Closed loop.

Oxides of nitrogen (NO_x)—A vehicle emission that is a combination of nitrogen (N_2) and oxygen (O_2), which are combined within the engine's combustion chamber or in the exhaust system due to temperatures that exceed 2500°F.

Oxygen (O_2)—A gas that makes up approximately 21 percent of Earth's atmosphere. Most of the oxygen that enters the engine's combustion chambers will be used up during combustion.

Palladium (Pd)—A silver-white, ductile, metallic element; number 46 on the periodic table.

Parallel hybrid—A vehicle that can be accelerated using either an electric motor/generator or a gasoline engine or both.

Parameter ID (PID)—A specific data stream parameter relating to a sensor value, an actuator command, or some other piece of information that a PCM or other control module may communicate to a scan tool through the data stream. The scan tool will show the PID as well as the related information.

Passive voltage—A voltage that is at rest, not being pulled either high or low by a computer circuit.

Permeability—A material that strongly demonstrates the characteristics associated with magnetism, such as iron, is said to have high permeability.

Pickup coil—A small coil of wire in which the signal of a pulse magnetic generator is produced, such as in many electronic distributors.

Piezoelectric—A crystal that produces a voltage signal when subjected to physical stress such as pressure or vibration.

Piezoresistive—A semiconductor material whose electrical resistance changes in response to changes in physical stress.

Pinpoint test—A test that checks a computer circuit for the exact fault, whether it be a sensor/actuator, an open or short in the circuitry, a poor or open electrical connection, or the computer itself. Pinpoint tests may be performed either by following a flowchart or by following an electrical schematic. Following a pinpoint test series, the technician should know exactly what repair needs to be made to restore the system to its "new" condition.

PIP signal—The profile ignition pickup signal (PIP) comes from a crankshaft- or distributor-mounted sensor indicating cylinder position to the computer.

Platinum (Pt)—A heavy, grayish white, ductile, metallic element; number 78 on the periodic table.

Polymer Electrolyte Membrane—A type of fuel cell that uses a solid polymer membrane (a thin plastic film) as an electrolyte. PEM fuel cells combine hydrogen (H_2) with oxygen (O_2) from atmospheric air to create electrical current flow. The only emissions resulting from fuel cell operation are water (H_2O) and heat. A PEM fuel cell is also commonly referred to as a Proton Exchange Membrane fuel cell.

Positive ion—An atom that has a deficiency of one electron, thus having fewer electrons than it has protons. It therefore has a positive electrical charge.

Potentiometer—A three-terminal variable resistor that acts as a voltage divider. Frequently used as a position sensor for throttle angle and so on. The potentiometer can be linear or rotary.

Potentiometer sweep test—The testing of a potentiometer throughout its range of operation to determine whether any electrical opens exist.

Powertrain control module (PCM)—The term and acronym now used (since OBD II) for the primary computer in charge of engine and transmission performance.

Pressure cycling switch—A pressure-operated switch in the low-pressure side of the air-conditioning system that opens as Freon pressure drops below a specific pressure. When the switch opens, the A/C compressor clutch is disabled. The purpose of this switch is to protect the compressor against operation when the system has leaked empty.

Primary and secondary oxygen sensors—The oxygen sensors are normal types, heated for rapid warm-up and closed-loop acquisition. What is new is the use of tandem sensors (also called primary and secondary oxygen sensors), one before and one after the catalytic converter. This combination serves as a test of the converter's effectiveness. So long as the downstream, secondary sensor shows a relatively flat signal, whatever its output voltage, the catalyst is working. When the secondary oxygen sensor starts the characteristic mixture dithering like the primary one (still used for fuel mixture trim), the catalyst has become inefficient.

PROM—Programmable read-only memory.

Propagation—As used in automotive technology, the spread of the flame front across the combustion chamber of an engine.

Protocol—A standardized binary code that constitutes the language with which computers are able to communicate with each other over a data bus.

Proton Exchange Membrane (PEM)—A type of fuel cell that uses a solid polymer membrane (a thin plastic film) as an electrolyte. PEM fuel cells combine hydrogen (H_2) with oxygen (O_2) from atmospheric air to create electrical current flow. The only emissions resulting from fuel cell operation are water (H_2O) and heat. The technical name for this type of fuel cell is a Polymer Electrolyte Membrane fuel cell.

Pulse width and duty cycle—Both pulse width and duty cycle are measurements of a solenoid's (or signal's) on-time—pulse width as a real-time measurement and duty cycle as a percentage of the total cycle. If the frequency of the cycle is known (as measured with a Hertz meter), dividing the frequency into 1000 ms (1 second) determines the length of one cycle. If this amount is then multiplied by the percentage of duty cycle on-time, the result is the pulse width as a real-time measurement in milliseconds.

Pulse-width modulated (PWM)—A signal that is controlled according to a real-time measurement, usually in milliseconds or microseconds. This type of signal may be used to control fuel injectors, cooling fans, and blower motors. When a serial data bus uses a fixed pulse width, typical with two-wire buses, the binary code is said to be a PWM signal.

Pulsed injection—One of the two kinds of fuel injector fuel-spray techniques, the other being continuous injection. In a pulsed injection system, the injectors are pulsed, in some way, according to the tach reference pulse of the ignition system. Therefore, as engine RPM increases, the frequency of the injector pulse also increases. TBI injectors may be pulsed with every tach reference pulse. PFI systems may pulse their injectors simultaneously (all at the same time), in groups (half at a time), in pairs, or sequentially in the engine's firing order just before the intake valve opens.

Pumping losses—The load on the engine caused by the work needed to pump air through the system. On gasoline engines, because of the vacuum developed behind the throttle, pumping losses are greatest at the most closed-throttle positions: idle and deceleration. The aerodynamic friction of air through the intake system also contributes to a lesser extent to the pumping losses, though that becomes the principal source at high speeds and open throttle. Diesel engines, because they are unthrottled, have very low pumping losses compared to gasoline engines.

Quad driver/output driver—A power transistor in the PCM, capable of working either four or seven different actuators (such as injectors or ignition coils). Each quad driver or output driver works when the PCM uses it to ground a component's circuit, completing it.

Quick test—The whole set of procedures that make up the Ford diagnostic procedure.

RAM—Random-access memory.

Rationality testing—The diagnostic testing performed by a computer using its ability to compare input values to each other, or to operate an actuator while watching the change in a related input circuit. Also known as *efficiency monitoring.*

Rear Electronic Module (REM)—A Ford control module that controls the exterior lighting at the rear of the vehicle, as well as the deck lid release solenoid.

Reference voltage regulator—The device within a computer that generates the 5-V reference voltage used by the computer's internal circuits, including the logic circuits. Its signal, sometimes referred to as VREF, is also sent to those sensors that require it.

REF pulse—The basic timing signal sent to the computer, indicating crankshaft position. This signal is modified by the computer to set the actual timing.

Regenerative braking—The process of returning a moving vehicle's kinetic energy to an onboard battery when coasting or braking. This energy is then reused to get the vehicle moving again when reaccelerating, thus increasing fuel mileage. Brake life is also extended.

Reluctance—A material that does not demonstrate the characteristics associated with magnetism is said to have reluctance.

Resistance—Opposition to the flow of electrons; measured in ohms.

Rhodium (Rh)—A white, hard, ductile, metallic element; a member of the noble metals family; number 45 on the periodic table.

ROM—Read-only memory.

Scan tool or **scanner—**A diagnostic tool used to retrieve from a vehicle's computer memory any malfunction codes it has retained. On earlier systems, each manufacturer used a scan tool connector and setup unique to that manufacturer (though there are aftermarket scan tools with adapters that can read many of them). With OBD II–compliant vehicles, the scan tool is standardized and can be used for the same purpose on any vehicle. Many scan tools can also be used to get direct measurements of various sensors and to exercise various actuators to check on their effectiveness; also known as *functional tests.*

Schmitt trigger—A device that trims an analog signal and converts it to a digital signal.

Self-test—The self-diagnostic portion of the Ford quick-test in which the computer tests itself and its circuits for faults.

Semiconductors—Solid-state devices, such as diodes and transistors, that are formed from semiconductor materials that have four electrons in the valence ring. Depending upon design and applied polarity, they may either conduct electrical current flow or insulate against electrical current flow.

Sensor—All the inputs and outputs to the computer are either sensors that provide information or actuators that do work. Most sensors are sent a reference voltage that is reduced in a predictable way by whatever parameter they monitor. Some generate voltages of their own.

Serial data—Digitized code known as *binary code,* which is a combination of high and low voltages known as ones and zeroes, used as a language to communicate between computers or computer components.

Series hybrid—A vehicle that uses a gasoline engine to power a generator (or motor/generator) to provide additional electrical energy to the primary motor/generator to accelerate the vehicle.

Short-term fuel trim (STFT)—The PCM's immediate response to the oxygen sensor signal. When the oxygen sensor indicates a lean mixture, STFT increases its value to increase injector on-time. This causes more fuel to be added to the base fuel calculation and enriches the air/fuel mixture. When the oxygen sensor indicates a rich mixture, STFT decreases its value to decrease injector on-time. This causes fuel to be subtracted from the base fuel calculation and leans out the air/fuel mixture. Originally known on General Motors products as the "Integrator."

Signal (or voltage signal)—The voltage values that a computer uses as communication signals.

Single-point/multipoint fuel injection—Single-point injection refers to fuel injection using the equivalent of an electric carburetor. On four-cylinder engines, this usually involves a single injector, but on some V-form engines two injectors are combined in one unit. Also called *throttle-body fuel injection.* Multipoint fuel injection employs one injector for each cylinder.

Slave—A dependent node on a data bus.

Snapshot—A computer recording of information from sensors and actuators.

Soft fault—An intermittent fault whose symptom does not appear to currently exist.

Solenoid—A device with a movable iron core inside of an electromagnetic winding. The movable core is usually spring-loaded and will move against spring tension when the electromagnet is energized. It creates linear mechanical action and may be used to lock or unlock a door or engage a starter drive with a flywheel. It is often used to operate a valve to control the flow of air, vacuum, fuel vapors, or liquid, and may be spring loaded normally closed or normally open.

Speed density formula—A term referring to a method of calculating the flow rate and density of the intake air. The result of the calculation indicates the air's ability to evaporate fuel.

SPOUT—The Ford Spark Output (SPOUT) signal comes from the PCM and indicates to the ignition module when to fire the next spark plug. The exact timing is calculated on the basis of inputs from all the computer's sensors.

Star configuration—A configuration of a multiplexing network that connects the data bus to all nodes on the bus in a parallel circuit.

Star tester—A tester designed to test MCU and EEC IV systems; it activates and deactivates the self-test procedure and displays a digital readout of the service codes.

Stepper motor—A type of direct-current electric motor with the unique capacity to move an exact number of turns in response to a computer's signal. Typically, such a motor (used to adjust the idle speed bypass opening, for example) has a range of 256 different possible positions it can be set to. This allows the computer to open or close to an exact position. Such motors are also increasingly used in some heater door control systems.

Stoichiometric—In automotive terminology, refers to an air/fuel ratio in which all combustible materials are used, with no deficiencies or excesses; 14.7 parts air to 1 part fuel, by weight.

Technical Service Bulletin (TSB)—A repair procedure issued by the manufacturer that addresses a particular problem and instructs the technician on how to perform a proper repair so as to correct the symptom.

Test ID (TID)—An identification code, usually given as a hexadecimal value, that identifies a test relating to a component in a computerized engine control system. TIDs and their related information can be displayed using a scan tool. The related specifications may be looked up, many times at a manufacturer's Web site.

Thermac—The term used by General Motors to identify the heated air inlet system. The term is a shortened form of *thermostatic air cleaner.*

Thermistor—A temperature-sensing device whose resistance changes dramatically as the temperature changes. Most thermistors have a negative temperature coefficient (the resistance goes up as the temperature goes down).

Thermo-time switch—An electrical switch usually applied to a bimetallic strip that uses heat to open or close a set of electrical contacts. The amount of heat is controlled, so the time it takes to open or close the contacts is always controlled.

Thick film integrated (TFI)—A term that identifies the type of chip used in the ignition module attached to the side of the distributor for EEC IV system applications.

Throttle-body injection (TBI)—Throttle-body injection uses a single fuel injector in a throttle body (or a pair of two for V-form engines) that delivers the fuel to the intake manifold.

Throttle Plate Position Controller (TPPC)—An IC chip embedded within a Ford PCM, having the task of controlling the electronic throttle control (ETC) system.

Torque converter lockup clutch—A computer-controlled, hydraulically actuated clutch in the automatic transmission's torque converter that locks the transmission's input shaft to the engine's crankshaft for fuel economy. The computer determines when to send this command on the basis of sensor inputs.

Torque management—A set of capacities the engine control system has, allowing it to reduce engine torque output under specific circumstances. Its first strategy is to retard spark; in more extreme circumstances it can selectively shut off fuel injectors. The traction control system employs part of the torque management system to prevent front-wheel spin under power when the pavement is slippery.

Transistor—A semiconductor that consists of three semiconductor elements placed back-to-back. A transistor operates as an electronic switch with no moving parts and may be either PNP or NPN design.

Trigger—The characteristics that determine the instant in time that a DSO begins to display a waveform. These characteristics include trigger source, trigger level, trigger slope, and trigger delay (horizontal waveform position).

Trip—A key cycle consisting of Ignition On, Engine Run, Ignition Off, and PCM Power Down, during which the enable criteria for a particular diagnostic test are met and the diagnostic test is run by the PCM. A trip is used by the PCM to perform a diagnostic test to confirm a symptom or its repair.

Two-trip malfunction detection—On some vehicles, the computer waits to record certain faults until they appear on two separate driving trips.

Vacuum fluorescent (VF)—A glass tube containing anodes and a cathode. The anodes are coated with a fluorescent material and are positioned so they form all of the segments of alphanumerical characters. As current passes through the cathode, it gives off electrons. If the anodes have positive voltage applied, the electrons given off by the cathode are attracted to them and strike the fluorescent material, causing it to glow.

Valance ring—The outermost electron shell of an atom.

Variable cam timing (VCT)—A system that uses a cam phaser on the front end of the camshaft to change the camshaft's position relative to the crankshaft.

Variable Cylinder Management (VCM)—Honda's name for a variable displacement system to improve fuel economy, in which the PCM disables cylinders when engine load is light. The selected cylinders are disabled by turning off the fuel injector and then disabling the ability of the valves to open using a Honda VTEC-style rocker arm design, reducing pumping losses by allowing the cylinder to act as an air spring.

Variable pulse width (VPW)—The term assigned to serial data that consists of bits of information that are of more than one length. In this case, a "one" may be represented either as a short high-voltage pulse or as a long low-voltage pulse. Conversely, a number "zero" may be represented as a short low-voltage pulse or as a long high-voltage pulse. This allows the voltage to switch between high- and low-voltage values with every bit of information.

Variable valve timing (VVT)—The ability of a computer to vary valve timing using an actuator designed for that purpose to get best performance under high load conditions while still getting good engine response at low rpm.

Vehicle Control Module (VCM)—A General Motors PCM that, in addition to controlling the engine, transmission, and cruise control systems, now also controls the antilock brake system.

VIN entry mode—A diagnostic mode on a scan tool that allows the scan tool to recognize the particular make, model, and year of vehicle as well as other attributes such as engine identification and computer protocols using the the vehicle identification number (VIN), which is entered into the scan tool. This mode generally allows the technician to access the most diagnostic information using a scan tool. Not all aftermarket scan tools support this mode.

Volt—A unit of measurement of electrical pressure or electromotive force.

Voltage or voltage potential—A measurement of electrical pressure or electromotive force.

Voltage drop—The voltage that is used up as current flows through resistance in an electrical circuit.

Voltage drop test—A test that is a more precise substitute for resistance tests done with an ohmmeter. A voltage drop test checks the positive side or negative side of the circuit to measure precisely how much voltage is used up by the resistance in that portion of the circuit. It must be performed while current is flowing in a completed circuit. Excessive voltage drop indicates excessive unwanted resistance.

Volumetric efficiency (VE)—A measure of cylinder-filling efficiency. VE is expressed as the percentage of atmospheric pressure to which the cylinder is filled at the completion of the compression stroke. This efficiency varies with engine speed; the point of highest volumetric efficiency (which can rise above 100 percent in some cases) is the point of highest engine output torque.

Wastegate—A valve or door that when opened allows the exhaust gas to bypass the exhaust turbine of a turbocharger. The wastegate is used to limit turbocharger boost pressure.

Waste spark—An ignition system using one coil between every complementary pair of cylinders, firing both plugs simultaneously, one at the end of the compression stroke and the other at the end of the exhaust stroke.

Water (H_2O)—One of the by-products of combustion of a hydrocarbon-based fuel within the engine.

Wattage—A measurement of total electrical power. Volts times amps equals watts (known as Watt's Law).

WOT—Wide-open throttle.

Zirconium dioxide (ZrO_2)—A white crystalline compound that becomes oxygen-ion conductive at about 600°F (315°C).

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